VISION:

ITS

OPTICAL DEFECTS,

AND THE

ADAPTATION OF SPECTACLES.

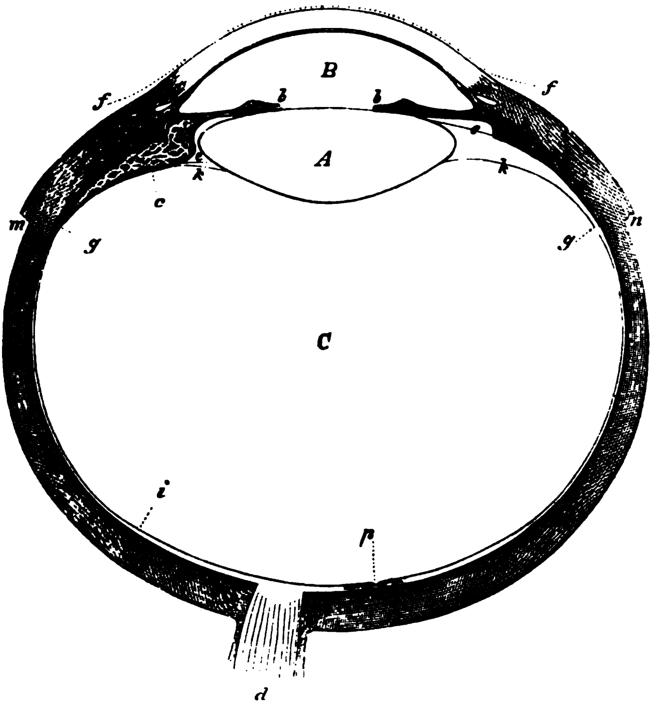

FIGURE OF THE EYE. (After HELMHOLTZ.)

1°, *B*, ***Aqueous humor*** in the anterior chamber of the eye.

2°, *A*, the crystalline lens.

3°, *C*, the vitreous body.

i, the retina.

e, the zonula zinnii.

g, the choroid.

h, the ciliary body.

b, the iris.

d, the optic nerve.

a, Schlemm's canal.

p, the fovea centralis.

k, the capsule of lens.

ff, the epithelium of cornea.

m, *n*, the insertion of muscles in the sclerotica.

VISION:

ITS

OPTICAL DEFECTS,

AND THE

ADAPTATION OF SPECTACLES.

EMBRACING

First. Physical Optics. Second. Physiological Optics.
Third. Errors of Refraction and Defects
of Accommodation, or Optical
Defects of the Eye.

WITH

SEVENTY-FOUR ILLUSTRATIONS ON WOOD,

AND

SELECTIONS FROM THE TEST-TYPES
OF JAEGER AND SNELLEN.

BY

C. S. FENNER, M.D.,

PHILADELPHIA:
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TO

DR. E. WILLIAMS,

OF CINCINNATI,

AND

DR. GEORGE STRAWBRIDGE,

OF PHILADELPHIA,

As an expression of high appreciation of their eminent ability and learning in this Department of Science, and in grateful acknowledgment of many favors,

THIS WORK

IS

Respectfully Inscribed

BY THE AUTHOR.

PREFACE.

IN preparing this work for the press, the endeavor has been made to give, in a concise and popular, yet comprehensive form, a *résumé* of our present knowledge of Physiological Optics and of the defects of the eye as an optical instrument. The views herein presented to the reader are believed to be, in general, strictly in accordance with Science as it is now known.

A brief elementary treatise on Physical Optics has been prefixed, as a knowledge of this subject is necessary in order to understand the explanations of many phenomena connected with the functions of vision.

The manuscript was commenced during the past summer; but, owing to an affection of my eyes,— retinal hemorrhage, — which came on suddenly before the writing of Part First was finished, the work is not as complete as was intended. Having since that time been unable to make much use of my eyes in reading or writing, I was compelled to complete the manuscript by dictating to an amanuensis, and to have my thoughts recorded, chiefly, as they were previously arranged in my mind, or from notes before taken, but without regard to order, not being able to refresh my memory, as the book

progressed, by more recent reading of authorities. I, however, hope the volume is sufficiently comprehensive to give much useful information to the student, the physician, and to those of the general public who desire to obtain an insight into this department of science.

I have been unable to read the proof-sheets carefully, and for their correction am indebted to Dr. Thomas E. Jenkins for the first part of the work, and for the other parts to Dr. H. Ruschhaupt and W. S. Macrae, Esq.

The drawings on wood for the engravings were supervised by Mr. Samuel L. Fox, of Philadelphia.

To all of those gentlemen, who have so kindly lent me their assistance, I tender my sincere thanks.

C. S. FENNER.

LOUISVILLE, KY., July 1, 1875.

CONTENTS.

PART I.

PAGE
PHYSICAL OPTICS 17
LIGHT 17

PART II.

PHYSIOLOGICAL OPTICS 68
VISUAL SENSATIONS 120
VISUAL PERCEPTIONS 140

PART III.

ERRORS OF REFRACTION AND DEFECTS OF ACCOMMODATION 168
HYPERMETROPIA 187
MYOPIA — NEAR-SIGHTEDNESS 215
ASTIGMATISM 247
DIFFERENCE IN REFRACTION OF THE TWO EYES 282

APPENDIX 285

A

TREATISE ON VISION.

PART I.

PHYSICAL OPTICS.

LIGHT.

IN order to comprehend the theory of vision, and to be able to investigate the various phenomena connected with the perceptions furnished by the sense of sight, it is first necessary to understand the nature and properties of light and its physical laws, that is, laws that exist independently of the human eye.

According to the now almost universally adopted theory, all space and the interstices of all material bodies are filled by a perfectly elastic medium of inconceivable tenuity, which, for want of a better name, is called *ether*. Luminous bodies have the power of incessantly imparting to this elastic medium vibrations, which move in undulations or waves. The refractive media of the eye collect and concentrate these waves, and throw them on the retina; the impulses falling on the delicate perceptive nervous elements — the rods and the cones — produce impressions, which are conveyed by the optic nerve to the brain, where a sensation of light is felt. These undulations of the elastic ether are not light, but they are the motions of matter that cause the sensation of light. The needle that pricks the finger is not the pain, but it is the motion of the steel, coming in contact

with a sensitive nerve, that causes the sensation of pain. Light, then, being but a sensation, it follows that if there were no nerves having the special sense of sight, there would be no light. It is not the vibrations of the elastic ether, set in motion by an illuminating body, that alone are capable of causing the sensation of light. It can be produced by a blow on the eye, by pressure of the finger, by the weakest electrical current, by increased pressure of the blood, by intoxicating or narcotic drugs; even the irritation of the stump of the optic nerve, after the eye has been removed, is capable of producing similar subjective effects, and persons unacquainted with the causes of these phenomena, after the enucleation of both eyes, often suppose that they see real beams of objective rays. Undulations of elastic ether that enter the eye may be either direct or reflected; in the former case, the waves pass straight from the independent source of illumination — as the sun, a fixed star, a lighted candle, etc. — to the eye, which experiences a luminous sensation, varying according to the intensity of the illuminating rays. In the latter case, the direct waves first impinge on other bodies, illuminating them, and are then scattered or irregularly reflected; some of these scattered waves, from each point of the object, enter the eye and are united in a point by the refractive media, just on a sensitive nervous filament of the retina. Those points of a visible object that send the greatest number of waves to the eye, produce the strongest impressions on the nerve upon which they fall; those that send the fewest cause the weakest sensation, while intermediate points produce sensations proportionate to the number of waves each respectively sends into the eye. There is an image, in lights and shades, of the object seen, and each nerve filament — a rod or cone — communicates to the brain the impression made on it; the latter takes cognizance of every separate sensation caused by the impression made on each nerve filament, arranges and unites them all so as to interpret their combined effect, and then, by projection

outward, the sensorium is enabled to perceive the existence, form, and position of objects situated in space.

Definitions — Movement of Light.

A ray is the smallest visible line of light.

A beam is a collection or bundle of parallel rays.

A pencil is a collection of converging or diverging rays.

Homocentric light is a beam or pencil arranged around a common central ray.

Light — or, strictly speaking, waves of ether — moves in straight lines. Rays emanating from an illuminating or an illuminated point always diverge; in nature there are no converging rays, neither are there any absolutely parallel, but those proceeding from bodies infinitely remote, as the fixed stars are so nearly so that the difference can only be mathematically expressed. To render diverging rays parallel or converging, they must be bent by a refracting or reflecting surface. As an illustration of the correctness of the assertion that light travels in straight lines, and that every visible point of an object throws off or scatters rays in every direction, the formations of inverted images of objects from light passing through a minute hole in the window-shutter of a darkened room, and falling on a screen, is an example. Every visible point of the object, as, for example, of a house, sends a ray through the perforation which falls on the screen; an inverted image is formed, which is an exact inverted representation in form and color of the object, each point in the former exactly corresponding in position to a similar one in the latter. The image is inverted because the rays cross each other at the perforation that admits the light.

Transparency and Opacity.

Bodies are said to be *transparent* when they transmit light freely, so that objects can be distinctly seen through them, as air, glass, crystals, etc. They are *opaque* when light does

not pass through them. Objects that break up the rays, but transmit a diffuse, softened light, as porcelain, ground- or milk-glass, etc., are *translucent*. They do not allow the details of the image to be seen through them, but only the shade of its outlines. No substance is perfectly transparent; all absorb or quench a part of the rays, while others are reflected or scattered. If an object should be perfectly transparent, it would not be visible, because there would be no scattered rays to pass into the eye. Newton estimated that horizontal sunbeams passing through two hundred miles of atmospheric air, possess only two one-thousandth parts of their original intensity. The most transparent glass quenches or scatters about one-twelfth of the rays impinging on it, and it is the scattered part of these that enables us to see the glass. Even the refractive media of the eye are not perfectly transparent. Neither are there objects perfectly opaque; the densest of metals, as gold, when beaten very thin, transmits a greenish light, and, if alloyed with silver, a purplish light.

Shadows.

Opaque bodies interposed between a source of light and a back ground, cast shadows on the latter. In consequence of the rectilinear motion of light, the form of the shadow will correspond to the outlines of the object, but its size will vary according to the distance of the object from the light, or of the screen from the object. That the edges of a shadow may be sharply defined, the light must come from a point; if it proceeds from a luminous surface, the borders of the perfect shadow are surrounded by an imperfect shadow, called a *penumbra*. This can readily be shown by a lamp having a flat wick so as to make a broad, thin flame. If the broad surface of the flame be turned towards a screen of white paper, held two or three feet distant, and a small body, as, for example, a knife-blade, a pen-handle, or a knitting-needle, be interposed, the real shadow will be seen surrounded by the penumbra; if the edge of the flame

be turned towards the screen, the shadow of the object will have its edges perfectly defined.

Law of Diminution of Light by Distance.

The intensity of illumination produced by rays diverging from a luminous point, diminishes or is enfeebled in proportion to the square of the distance. A screen one foot square, at one foot from a lighted candle, receives a certain number of rays, and is illuminated accordingly. A screen two feet square, at two feet distance, receives the same number of rays, but they are spread over four times the surface; consequently, each point on the second screen receives but one-fourth as many rays as a point on the first. So a screen nine feet square, at the distance of three feet, receives the same number of rays as the smaller one at one foot from the candle, but they are spread out or thinned so as to cover nine square feet; hence, the intensity of the illumination of the former is but one-ninth that of the latter. This is illustrated in Fig. 1. A represents the flame of a candle; 1, 2, and 3, screens of one, two, and three feet square, placed at

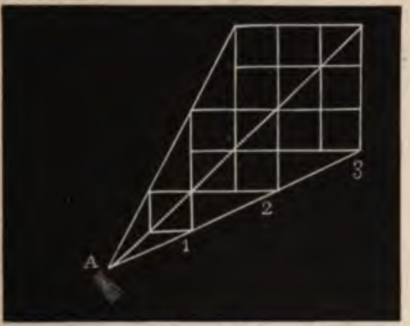


Figure 1.

corresponding distances from the flame. Each screen receives the same number of rays; but while at 1, they cover but one square foot; at 2, they spread over four square feet; and at 3, nine square feet.

Velocity of Light.

It requires time for the undulations of elastic ether to pass through space. According to the calculations of astronomers, light moves at the rate of about 192,000 miles in a second; hence, it requires a little more than eight minutes for the light, or the undulations of ether put in motion by the sun, to reach the earth. It is calculated that the light from the nearest fixed star is five years on its journey before reaching us, and telescopes reveal others many times more remote. The rapidity with which light travels is so great, that for distances, which we are able to measure on the earth, its passage seems instantaneous. It travels 900,000 times faster than sound in the air, and with 10,000 times greater velocity than the earth in its orbit.

Reflection of Light — Plane Mirrors.

When light falls perpendicularly on a plane polished reflecting surface, as a mirror, it is thrown back and exactly retraces its first course. If a ray strikes the surface obliquely,

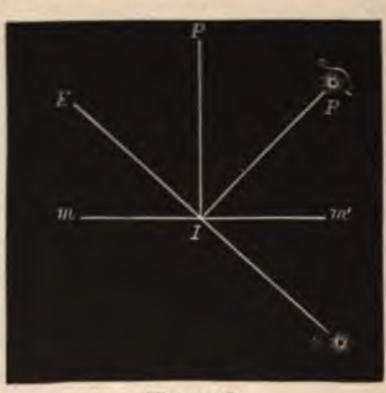


Figure 2.

it is reflected obliquely; the impinging and reflected ray each form a similar angle with a line perpendicular to the surface at the point of incidence; hence, the law which

applies to the refraction of light is expressed by saying, that "the angle of reflection is equal to the angle of incidence."

In Fig. 2, *m m′* represents a plane mirror; R I an incident ray, from a candle at R, falling on the mirror at I; I E the reflected ray; P I a perpendicular line drawn to the point of incidence at I; the angle R I P is equal to the angle P I E. The eye placed at E would see the candle at O, because it is a physiological law that the eye always locates the object in space in the direction of the rays that enter it. If the reflecting surface be unpolished, light falling on it is not regularly reflected, but is irregularly scattered or thrown in various directions.

The power of reflecting light varies greatly with different bodies. In some of the denser metals, nearly all of the light impinging on their polished surfaces is repelled; in black velvet, or charcoal, most of it is absorbed or quenched; very little is thrown back or scattered. If all the light should be absorbed by an object, the latter would be invisible, because there would be no rays left to enter the eye. No surface is absolutely flat or plane; the denser metals can be made to approach the nearest to this condition, for which reason reflection from their smoother surfaces is nearly perfect. When, by polishing, the minute elevations and depressions of the surface are reduced to the millionth of an inch, they seem to lose the power of acting separately, and produce the effect of a uniform surface. When the smooth surfaces of objects, like pressed white paper, polished wood, marble, etc., are examined with the microscope, they are found to consist of an infinite number of small planes, inclined to each other at all possible angles; these planes scatter the light in every direction; they produce what is called diffuse light. If a sunbeam pass through a perforation in the shutter of a dark room, and impinge on a highly polished metal plate, it is almost entirely reflected, and falls on the wall, making a bright spot the size of the beam, while the room still remains dark. If, for the mirror, a sheet of white

paper be substituted, the latter will be visible at any part of the room, and there will be a faint general illumination. It is these irregularly reflected, or scattered rays, that make non-luminous objects visible when they are illuminated. Different substances reflect light with greater or less perfection. Perpendicular rays falling on water have reflected 18 out of 1,000; glass, 25 out of 1,000; mercury, 666 out of 1,000. When rays strike the reflecting surface obliquely, a greater number are thrown back into the first medium; thus, at an incidence of 40°, water reflects 22 rays; at 80°, 333; at 89½°, 721 out of 1,000; the latter being about the same as is reflected by mercury at the same angle of incidence.

Position and Character of Reflected Images in Plane Mirrors.

In a plane mirror, the reflected image appears as far behind its surface as the object is in front of it; the former is a perfect representation of the latter in form, size, and color; but the image is laterally transposed, so that the left of the object becomes the right of the image, and *vice versâ*, the right of the former appears as the left in the latter; that is, as when compared with the visible face of the object, seen without the mirror, in place and position of the image. When we stand before a mirror, the left half of the face appears as the right in the image, and the right half as the left in the image. The reflected image of a printed page shows the letters arranged backwards, and from right to left; they appear just as the compositor arranges his type; if the image be received and reflected by another mirror, the letters of the page are again seen in their accustomed position for reading; so if the type be arranged for the press, a mirror enables us to read them the same as if their impressions were on paper. The object and its image are always on opposite sides of the perpendicular to the point of incidence.

A plane mirror gives an image of an object double its

height. If a mirror be moved in its plane, the image of an object moves twice as fast; so, if the mirror be rotated, the angle described by the image is twice that described by the mirror. The explanation is very simple. For illustration, suppose a ray from an object falls on a plane mirror at an angle of 22½°; it is reflected at an angle of 22½°; the angle of incidence and the angle of reflection combined form one of 45°. For the eye to see the reflected image, its visual line must form an angle with the incident ray at the point of incidence of 45°, or double the angle of incidence. Now we will suppose the mirror to be rotated 22½°; then the incident ray is rotated 22½° and the reflected ray 22½°; the eye must recognize a change of 45°, or twice the degree of rotation of the mirror, in order to see the image, and so for every other angle of incidence; hence, a mirror placed at an angle of 45° with the horizon, will cause horizontal objects to appear vertical and *vice versâ*.

Reflection from Curved Surfaces.

The law that the angle of reflection equals the angle of incidence, holds good when applied to regularly curved surfaces. Each point of the curved surface reflects a ray of light the same as a plane that is tangent to the curve at the point of incidence. If the mirror has a concave parabolic surface, rays parallel to its axis will converge after reflection, and cross each other on the axis at a certain distance from the reflector, and then proceed in a divergent direction. The point of crossing is called the *focus*, and its distance from the mirror the *focal distance*. Fig. 3, *m m′* represents a section of a parabolic concave mirror; parallel rays L R, L′ R′, L″ R″, will be reflected from it as from planes T T, T′ T′, T″ T″, tangents to the curve at the point of incidence of each respective ray. Incident and reflected rays enclose similar angles with R P, R′ P′, the perpendiculars to the tangents. All the rays cross at the focus F; R F is the focal distance of the mirror. If the surface *m m′* be con-

vex, parallel rays impinging on it will, after reflection, be divergent; traced backwards they would meet at F, which then becomes a *negative* focus.

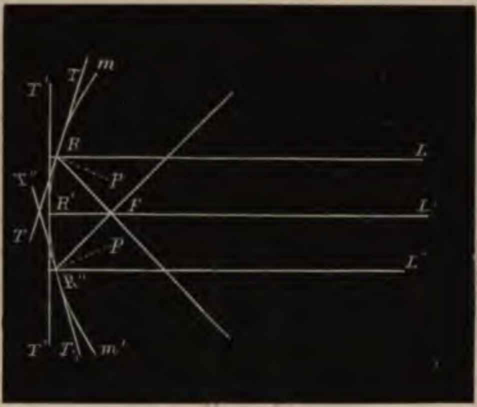


Figure 3.

Images Formed by Reflection from Curved Surfaces.

The image is formed in the focus of the rays proceeding from the object after being reflected; in the plane mirror the image is virtual, and as far behind as the object is in front of it. In the concave mirror the image is on the same side as the object; it is an actual image formed in the air, or it can be made to fall on a screen or a piece of ground-glass; in the latter case, it can be seen either in front or behind it. The position of the object and its focus is shown in Fig. 4. Let M N represent a concave spherical mirror, formed by rotating the curved line, having its centre in O, around the axis $x\ c$; O is the centre of a sphere, of which M N is a small section; $c\ x$ is its principal axis. A point of light placed at O, sending off rays that fall on the surface of the mirror at any point, as at m, is reflected back to O; if the point of light be removed to x, its rays, after reflection, will meet at x'; the image of x will therefore be at x'.

The angle of incidence O m x = the angle of reflection O m x'. Rays from a point of light at P, proceeding parallel with the axis c x, and falling on the mirror at m, meet at F, its principal focus. The image of P, therefore, is at F.

Figure 4.

Thus, it is seen that, while the point of light moves from O, the centre of the spherical surface, to an infinite distance, its focus only moves from O to its principal focus. If an object of sensible dimensions take the place of the point of light, when placed beyond the centre of the mirror, an inverted image of it of diminished size will be formed between the centre and the principal focus. A point and its image occupy positions which are convertible; hence, they are called *conjugate foci*. If the object be placed between the centre O and the principal focus, F, its image will be inverted, magnified, and situated beyond the centre. If the object be in the principal focus, the rays, after reflection, will be parallel, and no image formed; but the eye of an observer can unite these into an image on his retina, and thus sees a virtual, erect image of the object. The rays from objects placed between the mirror and its principal focus are reflected divergently, but if these be traced backwards, they will intersect behind the mirror, and form a virtual focus.

Aberration.—It is only the rays that fall on a spherical mirror near its axis, that are united in a point; if the sec-

tion of the sphere be large, the rays falling on it beyond a certain distance from its axis do not meet in the principal focus, but form there a luminous surface; this deviation of the rays is called *spherical aberration.* The luminous surface is called a *caustic*, and the principal focus the *cusp* of its caustic.

Refraction of Light.

When a ray of light, or a fasciculus of rays, passes from one homogeneous medium to another homogeneous medium of different density from that of the first, it is bent at the surface of separation, and proceeds in the second medium in a straight line, but in a changed direction. This is true of all rays that do not fall perpendicular to the surface of separation. Those rays which are perpendicular to the surface are not bent, but proceed through the second medium in an unchanged direction. Rays which fall obliquely on the surface, form an angle with the perpendicular at the point of incidence, called the *angle of incidence;* at the surface of the second medium the rays take another direction, and form a different angle with the perpendicular; this is the *angle of refraction*, which generally is not equal to the angle of incidence. These two angles, viz., the angle of incidence and the angle of refraction, always have definite and fixed relations to each other, and it is the enunciation of these relations that constitutes the laws of refraction. When rays of light pass obliquely from a rarer to a denser medium, they are generally bent *towards* the perpendicular; on the contrary, when they pass from a denser to a rarer medium, they are bent *from* the perpendicular. This is shown in Fig. 5. G G′ represents a strip of plate-glass with parallel surfaces; P P′ the perpendicular. A ray falling in the direction of P P′ passes through the glass unrefracted; B I an incident ray passing through the air — a very rare medium — and falling on the surface of the glass — a very dense medium — at I, at which point it is bent towards the perpendicular and

proceeds in a straight line to E; here it again meets with the air — the first medium — and is bent from the perpendicular, and continues in a line parallel to its first course.

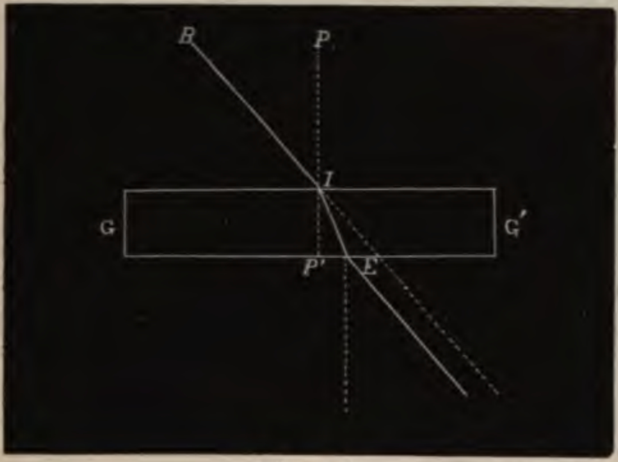


Figure 5.

The more obliquely the light falls on the refracting surface, the greater is the amount of refraction which its rays undergo; hence, the degree of refraction varies with the angle of incidence, but the relation that one bears to the other remains unchanged. For the same two media, the sines of the angle of incidence and of the angle of refraction always bear the same proportion to each other. The quotient obtained by dividing the sine of the angle of incidence *in vacuo*, by the sine of the angle of refraction, gives for any medium its *index of refraction*. The application of this law for water is shown in Fig. 6. A B C D represents the vertical section of a cylindrical vessel half filled with water, its surface being at A C; E is the centre; B D is a line perpendicular to the surface of the water at E; a ray from B would follow this line, and consequently pass unrefracted, or in a straight line. A ray entering the cylinder at *m*, and falling on the surface of the water at E, has its

direction changed at this point and passes through the water to n. At m draw the line $m\,o$ perpendicular to B D, and at n draw another line $n\,p$ perpendicular to B D. Whatever may be the angle of incidence, the lines $m\,o$ and $n\,p$ always have a fixed relation to each other; hence, $\frac{m\,o}{n\,p}$ is a constant quantity; x is the angle of incidence; y the angle of refraction. The dotted lines represent light falling at another angle of incidence, but the ratio of $m'\,o'$ to $n'\,p'$ is precisely the same as that of $m\,o$ to $n\,p$.

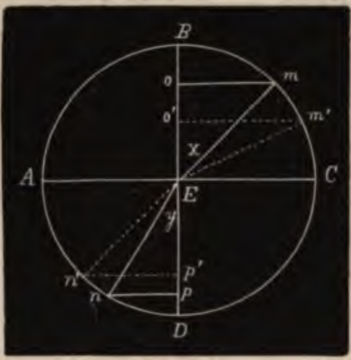


Figure 6.

If we regard the radius of the circle A B C D as a unity, or 1, the line $m\,o$ will be the sine of the angle of incidence, while $n\,p$ will be the sine of the angle of refraction; hence, the law. The sine of the angle of incidence, divided by the sine of the angle of refraction, is a constant quantity, which quantity invariably determines the index of refraction. Rays passing backwards always retrace their first course; this is a universal law of optics. The indices of refraction of the following substances are here given, the light being supposed to pass from atmospheric air.

Diamond	2·429	Ether	1·358
Rock Salt	1·557	Water	1·335
Quartz	1·548	Ice	1·308
Alcohol	1·372	Oil of Turpentine	1·476

It will be seen that oil of turpentine has an index of refraction greater than that of water, although its density is to that of water as 824 is to 1000. A ray of light passing obliquely from turpentine into water is bent from the perpendicular; hence, this is an exception to the general law. Combustible substances usually refract light with the greatest

energy. For this reason, Newton conjectured that diamond, owing to its index of refraction being so high, "was probably an unctuous substance coagulated." Diamond is now placed among combustible bodies.

Total Reflection.

It has been previously stated that all of the rays of light impinging on a refracting surface do not enter it — a part are reflected or thrown back into the first medium. The larger the angle of incidence, the greater will be the number of reflected rays. There results from this law a singular phenomena, which has received the name of *total reflection*. If rays of light, passing through air, fall on the surface of water at an angle of a little less than 90° incidence, the angle of refraction in the water will be 48½°. On the principle of reversibility, if rays of light pass through water and fall on its surface at an incident angle of 48½°, it will not leave the water, but just graze along its surface. If the rays passing through the water meet its surface at a greater angle than 48½°, they will be totally reflected, and pass back into the water in such direction as to make the angle of reflection equal to the angle of incidence. It is evident that this phenomena could not result from rays of light passing from a rarer to a denser medium, as from air to water or glass. On the contrary, when rays pass obliquely through a medium, and at its surface meet one of lesser density, it is seen that there is a certain angle of incidence, varying in size with the relative density of the two media, where the angle of refraction becomes a right angle; the refracted ray will then pass along between the two surfaces. As the angle of refraction is greater than the angle of incidence when light passes from a denser to a rarer medium, it follows, that when the former becomes a right angle the latter is less than a right angle, and if from this position the angle of incidence be increased, the angle of refraction becomes greater than a right angle; consequently, the rays cannot leave the first

medium, but are totally reflected, and follow the established laws of reflection. The smallest incident angle at which the rays do not emerge from, but just graze, the surface, is called the angle of *total reflection*. This angle, for water and air, is 48° 27′; for flint-glass in the air it is 38° 41′; for diamond, 23° 42′. A very simple experiment shows that the effect produced by total reflection surpasses in brightness any image formed by reflection from mercury, or the most perfectly polished metal-plate. If we place a bright piece of silver coin in the bottom of a tumbler, and cover it with water to the depth of two or three inches, then tilt the tumbler so as to obtain the necessary angle of obliquity to the surface, by looking upwards through the water the coin will appear at the surface as bright and shining as if seen by direct vision. If rays of light fall perpendicularly on the side of a right-angled isosceles prism, they will enter and fall on the hypothenuse at an angle of 45°; this exceeds the limiting angle of glass; hence, the rays will be totally reflected at an angle of 45°, and will form a right angle with the incident rays. This law of refraction is often utilized in the construction of optical instruments. The binocular ophthalmoscope of Giraud Teulon acts on this principle. As the opening in the ophthalmoscopic mirror must necessarily be small, and requires to be, when in use, very near to the eye, as a matter of course, but one eye can be applied to it at a time; hence, the ordinary instrument can only be used in monocular vision. Giraud Teulon placed two rhomboidal prisms behind the opening in the mirror, as represented in Fig. 7. M M′ represents the mirror with a small hole in its centre; A A′ two rhomboidal prisms. These prisms are placed in apposition behind the mirror, as seen in the figure. I I′, a bundle of parallel rays passing through the mirror. Ordinarily these rays enter the eye of the observer at O, but here they are divided; one-half falls on the right-hand prism, the other half on the left-hand prism. They pass without change of direction until they arrive at P P′, the hypothe-

nuse of the prism; here each is totally reflected at angles of 45°, one-half passing to the right the other half to the left, when each falls on another hypothenuse, where they are

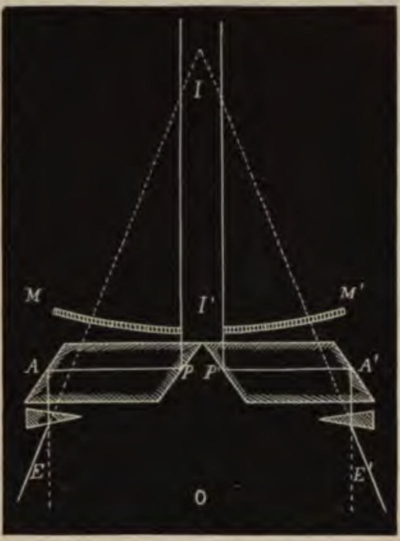


Figure 7.

again reflected at angles of 45°. The divided fasciculus now passes out of the prisms, and the rays assume directions parallel with their first course. The eyes of the observer, placed one at E the other at E′, see with both that which, under other circumstances, could be seen with but a single eye, thus giving the advantage of binocular vision, a matter of great importance in studying the topographical positions of the structures at the fundus of the observed eye. The wedge-shaped prisms are added in order to render the parallel rays slightly divergent, so as to assist the eyes in fusing the double images.

The mirage of the desert is partly due to total reflection. The hot sand heats the air in contact with it, which becomes rarer than that which is superincumbent. Rays from distant objects striking the latter very obliquely, are totally

reflected, and meet the eyes in such a manner that the object is seen the same as was the silver coin on the surface of the water, in the experiment with the tumbler, referred to above. It is to total reflection that diamond chiefly owes its extraordinary brilliancy; owing to its very high refractive power, total reflection commences at small angles of incidence; all of the rays filling an angular space of 90°, in the air, are in the diamond condensed into an angular space of 23° 42′. The effect of total reflection can be shown by placing in an opening made in the window-shutter of a dark room a rectangular isosceles prism, so that one side shall look outwards and be parallel to the shutter, the other resting on a side of the tube forming the hole, while the hypothenuse looks into the room. The strongest light from the exterior, shining on the prism, is totally reflected by the hypothenuse of the prism, and falls on the surface of the tube, where it is either quenched or reflected back in the course of entrance. The room remains perfectly dark; not a ray of light enters it.

Refraction by Curved Surfaces — Lenses.

The term lens was first applied to a transparent refracting body, having two regularly spherical surfaces, on account of its resemblance to a leguminous vegetable known in the East as a lentil. It is certain that convex lenses were in use among the ancients, and then, as at the present day, they were used to magnify small objects. They have been found among the debris of Nineveh, and among the ruins of Herculaneum and Pompeii. The term lens is now applied to all transparent masses terminating at least on one side by spherical or cylindrical surfaces; these may be either convex or concave. When the term lens is used, it is generally understood to be a bi-convex one, unless otherwise specified; but to be accurate, it should, when expressed by its numerical power, be preceded by the sign of plus; as, for example, $+\frac{1}{10}$, which signifies that it is a convex lens of

10 inches focus. The concave lens is designated by the sign of minus; as $-\frac{1}{10}$, meaning that it is a concave spherical lens of 10 inches negative focus. Convex lenses cause parallel rays of light passing through them to converge towards a point; or if they be already convergent, they increase the degree of convergence. Their action is said to be positive. By the French they are called *loupes.* Concave lenses, on the contrary, cause parallel rays to diverge, or they increase the dispersion of rays already divergent. Their action is negative. Positive lenses are thickest at their centres. Negative lenses are thinnest at their centres. The different forms of positive and negative lenses are represented in Fig. 8.

Figure 8.

A, a *plano-convex,* one of its sides plain, the other convex; B, a bi-convex, both of its sides are convex; C, a positive or concavo-convex meniscus, having one side concave the other convex, but the convex side has the shortest radius of curvature; D, a plano-concave lens, one of its surfaces plain the other concave; E, a bi-concave, both of its surfaces are concave; F, a convexo-concave or negative meniscus, one of its surfaces convex the other concave, but the concave surface has the shortest radius of curvature. The principal axis of a lens is a straight line — as $x\,x'$ — drawn perpendicularly to the curved surfaces — at the place of its greatest thickness for a convex lens, or at its thinnest part for a concave lens. A secondary axis is one which cuts the principal axis in the middle of the maximum thickness or thinness of the lens; consequently, a ray of light passing

through a secondary axis must form an angle with the principal axis. The secondary axis ray is not a straight line, but a refracted one, the emerging ray taking a direction

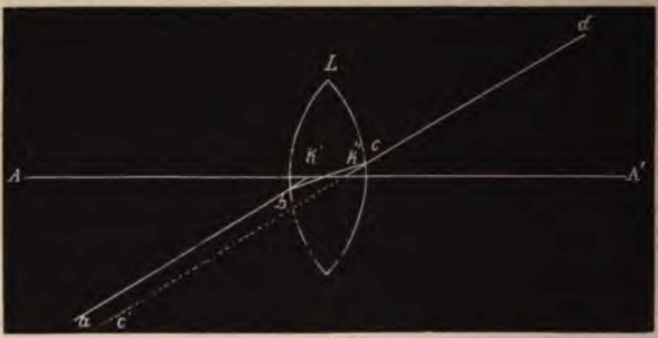


Figure 9.

parallel with its course of incidence. This is shown in Fig. 9: L represents a bi-convex lens; A A′, a ray passing unrefracted through its axis; *a b*, an incident ray falling on the anterior convex surface at *b*, where it is refracted and proceeds towards *c*, at which point it is again bent from the axis ray, and takes the direction of *c d*, parallel with its first course *a b*; *a b c d* is a secondary axis ray. The optical centre of a lens is at a point on its principal axis where all the secondary axes cross each other. For bi-convex and bi-concave lenses, where the radii of curvature of both sides are equal, the optical centre is at a point equally distant from either of the two surfaces. k' is the anterior, and k'' is the posterior nodal point. If the radii of curvatures of the two surfaces be unequal, it is nearest to the surface having the shortest radius; in plano-convex and plano-concave lenses, it is on the surface of curvature. In converging and diverging meniscus lenses, the optical centre may be outside of the refracting body.

When parallel rays—as those from the sun—pass through a convex lens, as L, in Fig. 10, the axis ray A A′ passes without being refracted; all of the other rays are bent towards

the perpendicular in such a manner that they unite on the axis ray at F′. F′ is the principal focus of L. The distance of F′ from *o*, the optical centre of the lens — as seen

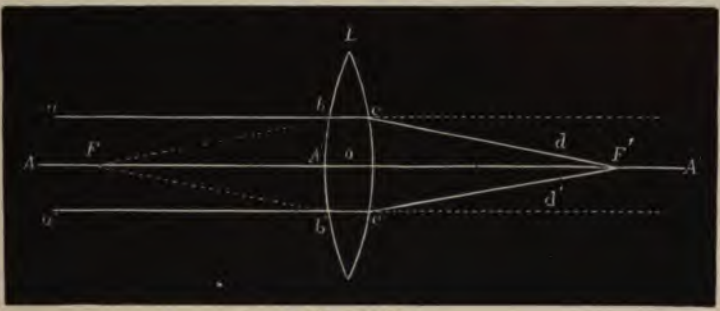


Figure 10.

in the figure — is its principal focal distance, and its measure represents the power or strength of the lens; thus, $\frac{1}{10}$ or $\frac{1}{12}$ means that F′ is situated 10″ or 12″ from *o*. A lens of $\frac{1}{4}$ signifies that its focal distance is 4″.

Rays of light from a luminous point placed at F″, in passing through the lens, become, on emerging, parallel, according to the principle of reversibility, and proceed as *b a*, *b′ a′*. Parallel rays, as the dotted lines in the figure, falling on the posterior surface of the lens, are united in a focus at F; this is the anterior focus, and is measured by its distance from *o*.

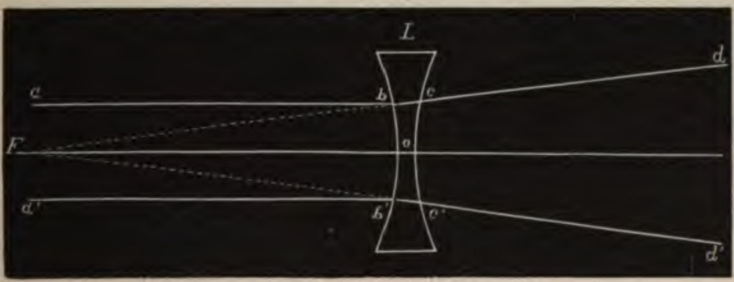


Figure 11.

Figure 11, L represents a bi-concave lens. Parallel rays *a b*, *a′ b′*, falling on its anterior surface at *b* and *b′*, on emerg-

ing from its opposite side at *c c'*, are rendered divergent, and proceed in the direction of *d d'*. These rays, traced backwards, meet the axis ray at F in front of the lens, or on the same side as the object from which the rays proceed. F is the negative focus of the bi-concave lens L. Convergent rays, as *d c*, *d' c'*, entering the posterior surface of the lens, will, on emerging from its anterior surface, become parallel, as *b a*, *b' a'*.

The focal distance of a lens depends on the index of refraction of the substance of which it is composed, and on the degree of curvatures of its surfaces. The shorter its radii of curvatures, the less is its focal distance.

If a point of light be placed at a finite distance, but farther than the anterior principal focus of the lens, its diverging rays will meet in a point beyond the posterior principal focus. If the point of light be brought nearer than the principal focus, the diverging rays, after passing through the lens, will still be divergent, but to a lesser degree. These rays traced backwards will meet at a point on the axis, in a virtual or imaginary focus, situated on the same side of the lens as the object. This is shown in Fig. 12. L, a bi-convex

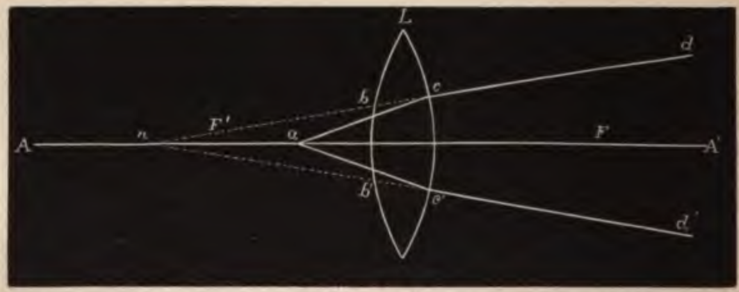


Figure 12.

lens; A A' its axis; *a*, the point of light nearer the lens than its principal focus F. The divergent rays *a b*, *a b'*, after passing through the lens, are still divergent, though to a less degree. These rays traced backwards, as shown by the dotted lines, meet in a *virtual focus* at *n*, on the same side of

the lens as the object *a*, but farther off than its principal focus F′. The real focus is always on the opposite side of the lens to the object, and becomes an optical image of the luminous point. The object and its image always have a reciprocal relation to each other; they are convertible. If the point of light be placed in the position of its image, the latter is reformed exactly in the place occupied by the former; hence, the object and its image are points of conjugate convergence, and to express this reciprocal relation, the points are called *conjugate foci;* the term has the advantage of rendering it unnecessary to state which of the two points is luminous. For the laws of refraction it is immaterial whether the point of light proceeds from an independent luminous source, or from a body which diffuses incident light; to form an image, it is necessary that light emanating from a point should, after refraction, unite in a point. When the object, instead of being a point, is of sensible size, and it is placed anywhere from a little beyond the principal focus to an infinite distance, an actual inverted image is formed in the air on the opposite side of the lens, at its conjugate focus. The eye, if placed beyond this aerial image, so that its visual line shall correspond with the axis of the lens, sees it as an actual image. If a screen of ground- or milk-glass be interposed in the focus of the rays, the actual image is formed on it, and it is visible to the eye placed either before or behind the screen. Images that are real cannot be formed by a concave lens; its focus is always virtual or imaginary, and in front of the lens.

Formation of Images.

To explain the manner of the formation of images of luminous or illuminated bodies of sensible size, when placed before convex lenses, we must trace the course not only of the axis ray and of the rays meeting in a focus on it, but we must also trace the course of all the secondary axes, and of the rays uniting on them, from each point of the object. Fig. 13, L represents a bi-convex lens; A B C, an arrow beyond

the principal focus, with its point upwards. The rays A o A′ and C o C′ are secondary axis rays. All rays from the point at A that enter the lens are united in a point on the axis ray A o A′ at A′; hence, A′ is the image of the point A. So with the point C; all of its rays passing through the lens are united on its secondary axis at C′, which becomes the image

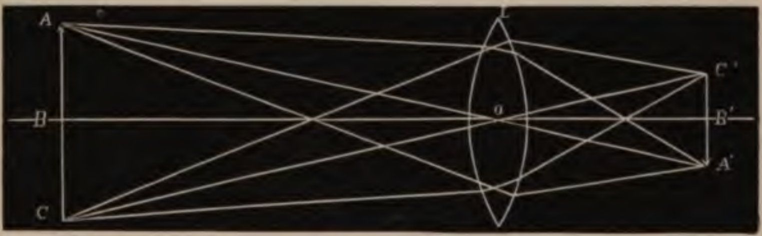


Figure 13.

of the point C. In the same manner each point of the surface of the arrow, looking towards the lens, has its image formed at corresponding points in the plane between A′ and C′; thus, A′ B′ C′ is the inverted image of the arrow A B C; inverted, because all the secondary axes cross at o, the optical centre of the lens. The image in the figure is smaller than the object. If the object be placed at 20′ or more distant, the inverted image will be of minimum size and at the principal focus of the lens. If, now, the object be made to approach the lens, its image will recede from it and increase in size, but with diminished brightness, until, when the object arrives at double the distance of the anterior principal focus, the image will be at the same distance behind the lens and of the same size as the object; as the latter is brought still nearer, its image recedes more rapidly with increasing size, but diminishing brightness, until it arrives at the principal focus, when there is no longer an image, but in place of it diffuse light, because the emerging rays are parallel. When the object is brought nearer to the lens than its principal focus, the emerging rays will be divergent; but if traced backwards, they form a negative focus on the same side of the lens as the object. The eye, so placed as to

receive these divergent rays, by accommodation unites them in an image on its retina, and sees an erect magnified virtual image of the object in the position of the negative focus. The only real image is the one formed on the retina of the observing eye. This is the principle on which objects are magnified by lenses, as illustrated by Fig. 14. A B repre-

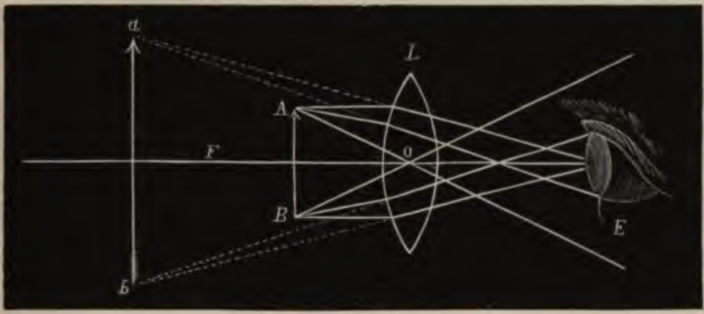


Figure 14.

sents an arrow with its point upwards; L, a bi-convex lens; F is principal focus. Rays from A and B, after passing through the lens, are divergent. Traced backwards, they meet behind the object at *a* and *b;* the eye, placed at E, sees the arrow erect and magnified seemingly at *a b*. A real inverted image of A B is formed on the retina, but the imagination refers it to the position of *a b*.

Spherical Aberration.

All the monochromatic rays emanating from a point, after being refracted by spherical surfaces, do not unite exactly in a point, but only approximately so. It is only for very small angles of incidence that the union is perfect; it becomes less and less so as the angles of incidence increase in size; those rays that are nearest to the axis of the lens are refracted least, and have a greater focal distance, while those rays passing through the lens near its periphery are refracted most, and unite at a point on the axis nearer than the central rays, as is shown in Fig. 15. L, the lens; A A′ its axis; *a a′*, *e e′*, rays near the axis

falling on the spherical surface at small angles of incidence, which are united at F, the principal focus of the lens; *c c′*,

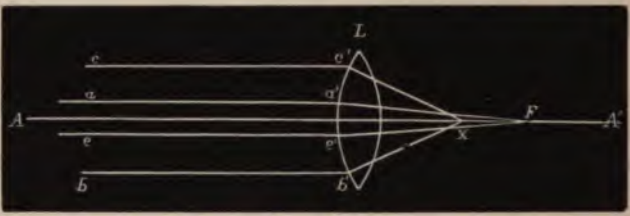


Figure 15.

b b′ are rays falling on the surface of the lens near its circumference, at large angles of incidence; they are more highly refracted and unite in *x*. Intermediate rays unite at intermediate points between F and *x*. This irregularity in the union of rays emanating from a point after passing through a spherical refracting body, is called *spherical aberration*. In the figure, the measure of the distance between F and *x* is the amount of spherical aberration of the lens L. A lens so constructed as to bring all the rays from a point impinging on it to a point is called *aplanatic*. As spherical aberration greatly interferes with the sharpness of the contours or borders of images, in optical instruments the peripheral rays are excluded by means of a diaphragm; the latter is perforated to form a central opening of sufficient size to admit the more central rays, thus securing distinctness and sharpness of outline at the expense of brightness. This diaphragm exists in the eye in the form of the iris, and the central opening corresponds with the pupil.

Chromatic Aberration.

Owing to the colored rays composing white light having different degrees of refrangibility, their points of convergence are not at precisely the same distance behind the lens, so the images belonging to the different colors do not exactly superpose. This is called *chromatic aberration*. This mani-

fests itself in proportion to the extent of the surface of the lens exposed to the light, being much greater for rays passing near its periphery than for those near the axis. Chromatic aberration is easily shown by taking a strong bi-convex lens of — for example — two inches focus, and holding it in the direct sunlight, and converging the rays on a piece of white paper. The violet and blue rays being the most refrangible, are first united in a focus, while the least refrangible, red, meet at a greater distance behind the lens. The converging cone is then surrounded by a sheath of the less refrangible red, so that if a screen be interposed in front of the focus, the illuminated spot will be surrounded by a sheath of red, within which is a circle of orange rays connecting it with the central white image. If the screen be placed immediately at the focus of the middle rays, the dispersion will scarcely be perceptible; but if it be removed to the focus of the red rays, the image will be surrounded by a circle of blue, from the blue rays which have crossed and are now diverging; thus, while the converging rays are surrounded by a sheath of red, the diverging cone has an outside sheath of blue. Newton entertained the opinion that chromatic aberration could not be overcome; he considered the degree of refraction proportional to the dispersive power of a prism or lens, and that if one be neutralized, the other would be destroyed also. Euler, as early as the middle of the seventeenth century, thought that chromatic aberration could be obviated, and a Swedish mathematician proved it theoretically, but it remained for Dolland, of England, to solve the problem by actually making an achromatic lens, and applying the same to the construction of telescopes. Two prisms, causing very different degrees of dispersion, may produce the same mean degree of refraction. By diminishing the angle of the more highly dispersive prism, its dispersive powers may be reduced to correspond with the feebler dispersive one; then, by placing them in apposition to each other, it is found that the colors of each are neutral-

ized without destroying the refraction. A prism made of crown-glass, opposed by one of flint-glass, is achromatic; the flint-glass neutralizes the dispersion of the crown-glass before it destroys the refraction. Achromatic convex lenses are made by opposing to lenses of crown-glass, concave ones of flint-glass, the residuum of refraction giving a colorless image.

Refraction at Inclined Surfaces.

When light passes through a refracting substance — as glass — whose surfaces are inclined to each other,— wedge-shaped,— the rays, after leaving the second surface, do not take a course parallel with their direction in the first medium, but a changed one. A refracting body having this shape is called a prism, and the angle enclosed between the two inclined surfaces its *refracting angle*. The amount of deflection of the ray from its original direction varies with the size of a refracting angle. The amount of refraction in the same prism varies with the course of the ray through it. When the direction of that portion of the ray within the prism forms equal angles with the perpendiculars to the two surfaces, the total refraction is at a minimum. When an object is seen through a prism, the eye locates it in the direction of the rays entering the pupil. Fig. 16 represents the vertical section of a prism. A ray from a point of light at

Figure 16.

L falls on one refracting surface at a, where it is bent towards the perpendicular P a, and proceeds straight to C, where it meets with another inclined surface at C, and is bent from

the perpendicular P′ C, and passes to the eye at E. The point of light is seen apparently at I, in the direction of the ray E C.

If the refracting angle be very large, light, in passing through it, has its constituent rays separated or *dispersed*, forming what is called a *prismatic spectrum*. If a beam of sunlight, passing through a small hole in the shutter of a dark room, impinges on one of the surfaces of a prism, each of whose angles measures 60°, and, after passing through the inclined surfaces, it be received on a white screen held a few feet distant, it will be seen that the sunlight has been decomposed by the refracting surfaces, and seven different colors will appear on the screen, each one always having a definite and fixed position in relation to all the others. The series of colors on the screen constitutes the *solar spectrum*. Prismatic analysis shows that a sunbeam is composed of seven different colored visible rays, besides some that are invisible, which are known as *heat* rays and *chemical* rays.

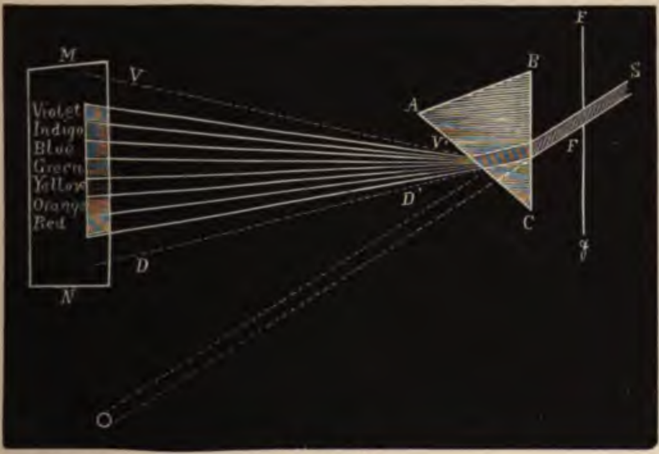


Figure 17.

In Fig. 17, S represents a sunbeam passing through F, an opening in the shutter E g, and falling on the prism A B

C, with a refracting angle downwards; M N, the white screen. "On viewing the spectrum attentively, we perceive that the lowest or least refracted extremity is a brilliant red, more full and vivid than can be produced by any other means, or than the colors of any natural substance. This dies away, first, into an orange, and passes, by imperceptible gradations, into a fine pale straw-yellow, which is quickly succeeded by a pure and very intense green, which again passes into blue, at first of less purity, being mixed with green, but afterwards deepening into the purest indigo. Meanwhile, the intensity of the illumination is diminishing, and in the upper portion of the indigo tint it is very feeble, but the blue is continued still beyond, and acquires a pallid cast of purplish-red, a livid hue, better seen than described, and which, though not to be exactly matched by any natural color, approaches most nearly to that of fading violet." (*Olmstead.*) If these colored rays be passed through a convex lens,—either spherical or cylindrical,—they may be blended, and form again, in the focus of the lens, the original white light. The same object can be accomplished by placing a second prism contiguous to the first, but in an inverted position. In the figure the dotted lines below the red rays represent the position of the invisible heat rays. The dotted lines above are the invisible chemical rays, or ultra-violet; as will be shown hereafter, these are not entirely invisible, but are very feebly illuminating rays.

Theories of Light.

Emission Theory.—The phenomena of light has been accounted for by two different hypotheses. The first and oldest of these is known as the *emission* theory; it is supposed that all luminous bodies are constantly throwing off into space infinitesimal particles of luminous matter, which travel with inconceivable velocity. These luminous particles of matter enter the eye direct, or they first fall on other bodies and are reflected; some of these direct or reflected particles are gathered up and concentrated by the refractive media of

the eye, form an image on the retina, and vision is excited or produced. This theory was advocated by Newton, and since his time by many eminent philosophers; among others, by Laplace, Malus, Biot, and Brewster.

Undulation Theory.— Upon the second hypothesis, the phenomena of light is accounted for by the *undulation* or *wave* theory. Every boy reared in the country is familiar with the phenomena of a circle of waves created by throwing a stone into the still waters of a pond. When his toy boat gets beyond his reach, he attempts to make it approach the shore by throwing stones beyond it, thus causing waves to arise on the surface of the water. The first wave that reaches the boat causes it to rise; as that wave passes, the boat falls; each succeeding wave creates a vertical motion extending above and below the water level, so that the boat alternately rises and falls, but does not move in a horizontal direction. Another stone thrown creates another succession of waves, and the toy vibrates vertically, but does not get nearer the shore. Again, if one takes a rope a few feet in length, hanging vertically, the upper end being held in the hand, while the lower end is free, and a to-and-fro horizontal motion be given to the hand, the rope will be thrown into the form of a line of undulation or waves, which move continually from the top to the bottom. The undulating line is represented in Fig. 18 by the dotted curves. Each particle of the rope moves in a horizontal direction; perhaps this may be better illustrated by tying around the rope a piece of tape, at some point, as T, in the figure; it will then be seen that during the undulations the tape moves horizontally to and fro, and always remains at the same distance from the

Figure 18.

ground. If the hand moves in a straight line in a horizontal plane, the tape also moves horizontally in a straight line. If the hand moves in the horizontal plane in an elliptic or circular line, the tape will move in a horizontal plane around its position of equilibrium, following the form of the curve described by the hand. The above illustrations serve to show the mechanism of the wave motion of elastic ether. It will be seen that luminous waves travel in a direction perpendicular to the planes in which the individual particles of ether oscillate. In elastic fluids, as, for example, in air, the sonorous vibrations are propagated parallel to the direction in which the particles oscillate, as may be illustrated by placing side by side, in close apposition, a number of elliptic springs; if one end of the series be put in motion, this will pass from one to another, and the movement of the individual particles of each spring will be in the direction of the line of propagation.

When, in elastic ether, the vibrating particles move in straight lines, the light is said to be *polarized in straight lines;* if the motion is elliptical or circular, the *polarization is elliptical or circular;* two rays polarized in straight lines, the directions of oscillation being perpendicular to each other, are said to be *polarized at right angles.* Light is *non-polarized* when there is a uniform mixture of all kinds of polarized light emanating from a luminous source. Light is said to be *simple*, *monochromatic*, or *homogeneous*, when each particle of ether oscillates in the same track, in the same time, and with the same velocity; the time that it takes for a particle to make one to-and-fro movement is called the *duration of the oscillation.* Natural light that emanates from luminous bodies is not ordinarily simple or homogeneous light, having a constant duration of oscillation, but it contains innumerable waves, having constant successions of the most diverse durations or periods of oscillation; hence, ordinary natural light is a *mixture* of light, or *compound* light. In Fig. 18, the line A A′ represents the position of the rope at rest. When put in motion by the hand, the

dotted line $a\ b\ a'\ b'\ a^2$ represents the position the particles of ether at first assume, when simple, straight-line polarized light is propagated along the line A A′. The particles displace one another with uniform rapidity of motion, and the waves on the line A A′ are of uniform length. Each particle leaves the line A A′ in regular succession, and makes its horizontal to-and-fro movement in a uniform period of time. During the time of one oscillation the light travels the length of one wave, which comprises the distance between c and c'. The *length of a* wave is the distance which separates two corresponding points, as two consecutive portions of the undulating line. The intensity of light depends on the *amplitude* of the vibrations; by this term is understood the extent of the motion of the particles of ether to and fro across the line of propagation. The amplitude of vibrations diminishes as the distance increases; the intensity of light diminishes inversely as the square of the distance from the luminous source. Experiments show that the intensity of light is in proportion to the square of the amplitude of the vibrations; it is also proportional to the square of the maximum velocity of the vibrating particle, according to the law of inverse squares.

The wave theory of light was first adopted by Huyghens, and afterwards advocated by Euler, who thought that light, like sound, was the result of undulating motion. Young and Fresnel both entertained similar views. "These two eminent philosophers, while adducing whole classes of facts inexplicable by the emission theory, succeeded in establishing the most complete parallelism between optical phenomena and those of wave motion. The justification of a theory consists in its exclusive competence to account for phenomena. On such a basis the *wave* theory, or the *undulatory theory* of light, now rests, and every day's experience only makes its foundation more secure." (*Tyndall.*)

Every known phenomenon connected with light is now explained in accordance with the theory of wave motion,

and in the elucidation of the laws governing the movement of luminous waves, theory has pointed out phenomena that should occur, under certain specified conditions, provided it were correct, and experiments have invariably shown that theoretical predictions founded on these laws have proved true.

Prismatic Dispersion.

After having become thoroughly familiar with the undulation theory of light, we are now prepared to explain the phenomena of prismatic dispersion, producing the solar spectrum illustrated above.

The waves of ether generated by luminous bodies vary greatly in length. The time of propagation of all the luminous waves is uniformly and constantly the same in a homogeneous medium; hence, the shorter waves must vibrate with proportionally greater rapidity in order to keep pace with the movements of the longer ones, but this uniformity varies when light passes from one medium to another. Light waves are retarded, in passing through transparent bodies, in proportion to the density of the medium traversed. In the ether of space, and in gases, all rays or waves travel with equal rapidity; consequently, undulations of ether generated by the sun, on reaching the earth, give pure white light. In refracting substances, short waves are more retarded than longer ones; hence, the former are more highly refracted than the latter, so that when they emerge from the refracting body their courses are no longer the same. The cause of dispersion is thus explained. In the solar spectrum the red ray is refracted least, because the length of a red wave is only about $\frac{1}{39000}$ of an inch, while the length of a violet wave, which is refracted most, is the $\frac{1}{57000}$ of an inch; the waves forming the intermediate colored rays have each different lengths, varying according to their relative positions in the spectrum; it is the length of the ethereal waves that characterizes the different kinds of light. There being 39,000 undulations of the red ray to the inch,

and light travelling 192,000 miles in a second, it follows, that in a second of time 474,439,680,000,000 waves enter the eye and impinge on the retina to cause the sensation of red-colored light; an increased number causes the sensation of orange; the next increase gives yellow; then in regular order green, blue, indigo, and when the violet is reached, the number of vibrations that enter the eye in a single second of time amounts to 699,000,000,000,000; it requires this number of wave impulses to fall on the special nerves of vision to produce the sensation of violet-colored light. The sensation of a particular color, then, depends on the number of luminous waves which enter the eye in a given period of time. So in sound, the pitch depends on the number of air waves that reach the auditory nerve in a second. The result, in each instance, is caused by the action of mechanical forces on the nerves of special sensation.

Dark or Invisible Rays.

In referring to Fig. 17, it will be seen that the dotted lines D D′, V V′ represent rays that do not produce luminous sensations; hence, they are called *dark* or *invisible* rays; the least refracted ones, D D′ — the infra-red — are known as heat rays. The ultra-violet, V V′, are the most refrangible of all the rays of the spectrum, and are known as *chemical* or actinic rays. The undulations of the former are not sufficiently rapid to produce luminous sensations; those of the latter are too frequent to cause a sensation of light. All the luminous rays produce more or less heat, but the heating quality belongs in a much higher degree to the invisible infra-red rays. A most wonderful provision of nature exists to neutralize the effects of heat rays entering the eye, and prevent their reaching the delicate nervous structure. Otherwise the powerful direct or reflected calorific rays of the sun, concentrated on the retina by the refractive media of the eye, would destroy that organ. Becquerel states that Tyndall admitted into his eye a cone of concentrated calorific

rays, from coals heated to incandescence by an electric lamp. The illuminating rays were removed by passing them through a solution of iodine in sulphuret of carbon. He experienced no sensation of heat at the fundus of the eye, but if the rays fell on the lids, the sensation of heat was at once felt. A sheet of platina, placed in the position occupied by the eye, instantly came to a lively red heat. The immunity of the eye from the injurious heating effects of the calorific rays, is due to the fact that they are to a very great extent absorbed by the aqueous and vitreous humors; the aqueous and fluid part of the vitreous is composed of almost pure water, which is rapidly removed by absorption and renewed by secretion; hence, the absorbed heat is removed by constant transudation. Janssen and Frantz found by experiment that the fluid contents of the eye have the power of absorbing heat equal to that of water.

From ignited carbon points, the energy of the invisible calorific rays is about eight times greater than that of all the luminous rays combined, while in the direct light from the sun it is probable that the proportion of heat to the illuminating rays is much greater. Luminous rays can be quenched by passing the beam of light through some substance that absorbs them; the invisible ultra-red rays can then be brought to a dark focus, in which non-refractory metals can be fused and refractory ones heated to incandescence. These dark rays, then, become luminous, which, on dispersion by means of a prism, give all the colors of the spectrum. The illumination thus obtained is called *calorescence*. The rapidity of the vibrations of the dark infra-red rays is sufficiently increased to produce luminous sensations. The relative intensity of the calorific, luminous, and chemical rays is shown in Fig. 19. It is seen that the heating effect gradually diminishes from the red rays of the spectrum to the violet, at which latter color it is scarcely perceptible.

Heat rays are reflected from the surfaces of polished bodies

in the same manner as luminous rays; those not reflected or repelled may traverse a transcalent body, or they may be in part or wholly absorbed; in the latter case, the temper-

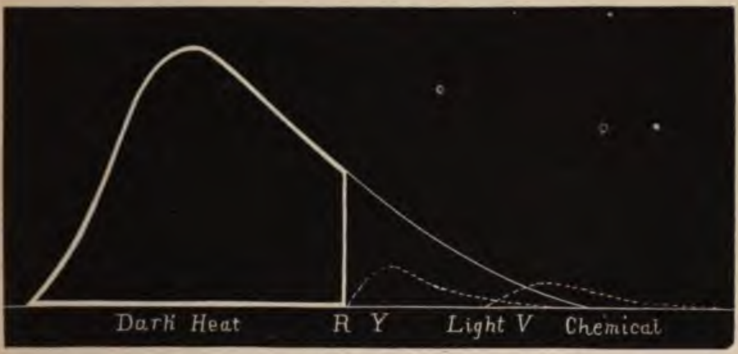


Figure 19.

ature of the body is increased. All bodies have the power of radiating or throwing off heat which they have absorbed. The absorbing and radiating powers of a substance for heat are regarded as equal.

Fluorescence.

The ultra-violet rays extend far beyond the limits of the ordinarily visible part of the solar spectrum, and are remarkable for their powerful chemical action. The rapidity of their vibrations is too great to cause, under ordinary circumstances, luminous sensations. If the number of vibrations producing these rays, can, for a given period of time, be lessened, their refrangibility is sufficiently decreased to cause them to fall in the luminous portion of the spectrum, where they cause sensations of light. This result can be accomplished by passing the chemical rays through a solution of the sulphate of quinine, which, in ordinary light, is colorless. The rapidity of the vibrations is diminished, and the solution becomes of a ghastly pale blue. This phenomenon is known as *fluorescence*. As the heat rays

become luminous by increasing the rapidity of their vibrations, on the contrary, the chemical become luminous by diminishing the number of their vibrations in a given period of time. Other substances besides quinine present in a high degree the phenomena of fluorescence, among which may be mentioned uranium-glass, aesculine, and platino-cyanide of potassium. Helmholtz states that if all the ordinarily luminous rays be completely excluded from the spectrum, the ultra-violet rays are directly visible to the eye without the intervention of a fluorescent substance; but this is very difficult to accomplish, because all refracting surfaces also reflect the light, and in all transparent substances, solid or fluid, a small quantity of light is irregularly diffused in all directions, which communicates to the field of vision a feeble illumination; it is white because the diffused light has not been decomposed. This light, although very feeble, is sufficiently intense to entirely mask the ultra-violet. Helmholtz has devised an apparatus, consisting of two prisms made of rock crystal — for glass sensibly absorbs the extreme ultra-violet rays — and two narrow slits, so arranged that the second only allows to pass the kind of light to be examined. The second prism receives the light after passing through the second slit, and throws it on a screen, or on a convex lens before reaching the screen. Under these conditions the extreme ultra-violet rays become luminous, and a considerable number of dark lines are visible in the spectrum. The cornea and crystalline lens are fluorescent, as can easily be shown by throwing the ultra-violet rays into the living eye; the lens then becomes so luminous that its position and form can be recognized behind the iris much better than by ordinary light. The fluorescent crystalline diffuses a large quantity of bluish-white light on the fundus of the eye, but fluorescent light does not give a sharply defined retinal image.

Phosphorescence.

Certain substances have the power of absorbing luminous rays when exposed to their influence; this result may be accompanied by chemical effects; sometimes it produces light, and, probably, always heat. If the chemical effect reproduces light, the body acted on emits light in every sense; it is different from absorbed light both in color and composition — the body becomes of itself luminous. This luminous state is called *phosphorescence* if it lasts longer than the action of the exterior light; and fluorescence, or true *interior dispersion*, if it ceases as soon as the exterior light is removed. The phosphorescence produced by exposing for some time certain mineral or organic substances to the action of solar or diffuse light, or from other luminous sources, shows itself by these substances becoming of themselves luminous, and shining in darkness, with a colored light dependent on the nature of their physical condition; the light which they emit gradually diminishes in intensity, until it disappears in a time varying from a few seconds to many hours. When again exposed to the action of light, the same effect is produced; the intensity of the light emitted is always much less than the incident light. Some substances, as the sulphate of strontian, of barium, and of calcium, give all the shades of the spectrum, from the red to the violet; the precious stones emit a yellow or bluish light. Becquerel states that he has seen a fragment of green fluorine and two white diamonds give out light for an hour after insolation, which indicates that these materials have a great *capacity* for phosphorescence.

The Pure Spectrum — Spectrum Analysis.

In the spectrum formed by an ordinary dispersing prism, the different colors overlap or run into each other; there is no sharp line of demarcation between them. In order to obtain a pure spectrum, in which the line of separation

between the different-colored rays is sharply defined, it is necessary to permit a thin slice of light, obtained from a beam passing through a very narrow slit in a metal plate, to be dispersed by a prism, and to increase the dispersion by means of one or more additional prisms. An instrument constructed for this purpose is called a *Spectroscope*, or light analyzer. Light, from whatever may be its source, in passing through the spectroscope, is decomposed, and the degree of refrangibility of its rays can be accurately determined. All gases, when heated to incandescence, and all incandescent vapors of metals, have each a spectrum peculiar to itself. In order to obtain the spectrum of a metal, as, for illustration, sodium, a piece of platinum wire covered with a solution of common salt — which contains sodium as its base — is introduced into the flame of an alcohol lamp; upon looking through the spectroscope, a bright yellow ray soon appears, which exclusively belongs to the spectrum of sodium. Lithium gives two principal rays—one a feeble yellow, the other a bright red; the characteristic rays of potassium are a red and a violet. Calcium gives a vivid green, an orange, and a blue ray. Strontian gives eight rays, six red, one orange, and one blue. Thallium gives a single line of green of exceeding brightness. All salts having metallic bases give the same spectrums as the bases themselves.

Fraunhofer's Lines.

Fraunhofer was a glass-cutter in Straubing, but, by hard labor and perseverance, he became one of the ablest opticians of his age. In 1817 he noticed the phenomena — previously discovered by Wollaston, according to English accounts — that the light of the sun, treated in the manner above described, does not produce a perfectly continuous spectrum; across its face he saw innumerable dark lines, caused by the absence of corresponding rays. These have since received the name of *Fraunhofer's Lines*. To account for their appearance in the solar spectrum remained for a long time an

unsolved problem. The mystery was finally explained by Kirchhoff. It is now an established law that every body is specially opaque to such rays as it can itself emit when heated to incandescence; hence, gases heated to whiteness, and the incandescent vapors of all metals, do not transmit light of their own color; when they surround a luminous body, the spectrum from the light is found to be intersected by numerous dark bands, between which are different-colored lights. The dark lines are produced by vapors, which absorb or quench the rays of light of their own color. The vapor of every metal, and of every incandescent gas, gives series of bright bands, each peculiar to itself, and unchangeable; hence, when their number, width, and positions in the spectrum are known for each vapor or gas, any one or more of the metals or gases can be detected and positively determined to be present in the atmosphere surrounding the source of illumination, by the arrangement of the dark lines according, both in number and positions, with the spectrum of these substances as seen in the spectroscope. Incandescent vapor does not transmit rays from a luminous nucleus which it itself emits; consequently, these are wanting, and their places are occupied by dark lines; these accurately correspond to the bright lines of the spectrum of the interposed body; remove the luminous nucleus, and the incandescent vapor gives to the dark lines the bright ones of its own spectrum. The spectoscope reveals many dark lines in the solar spectrum exactly identical, both in number and position, with the bright spectrum of many earthly bodies when heated to incandescence; hence, it is proved beyond a doubt that these substances are mingled with the solar atmosphere. The presence around the sun of hydrogen, copper, zinc, chromium, nickel, magnesium, barium, calcium, and sodium is thus rendered certain. The same method of observation reveals to us the fact that many elementary constituents of the planets, fixed stars, comets, and nebulous formations are identical with those existing in this little spot

in creation — the earth — and that the latter is thus shown to be but a fragment of one stupendous whole, formed from identical chemical constituents. It is just what astronomers have for a long time suspected, but only recently absolutely proved by spectrum analysis. No star of sufficient brightness to form a spectrum has yet been found that does not give dark lines indicating the presence of earthly constituents. The atmosphere of the star Aldebaran indicates the presence of hydrogen, sodium, magnesium, calcium, iron, bismuth, tellurium, antimony, and mercury. The atmosphere of the star Alpha Orionis contains sodium, magnesium, calcium, iron, and bismuth.

Phenomena of Interference.

A circle of waves, created by throwing a stone on the still water of a lake, was referred to above as an illustration of the undulatory theory of light. To illustrate the phenomena of interference, two stones may be simultaneously cast on the water, and falling some distance apart, two concentric circles of waves will be created, as shown in Fig. 20, having

Figure 20.

their origin in the points A A′. If the amplitude of each system be the same, the advancing wave of each will meet at a point equally distant from the two centres, as at *e*; here the elevation will be doubled; the combined waves will form

one of twice the amplitude of either before meeting. The first depression, or sinus, of one system reaches the point *e* at the same time as the first sinus of the other system of waves, and through their joint action the depression is double that of either sinus taken singly. The same results follow the meeting of all corresponding crests and sinuses of the two systems. When these do not correspond there will be a certain point where the ascending wave of one system meets the descending wave of the other system; at this point the water will remain at rest, because one wave just neutralizes the other. Neutralization of forces takes place when one wave is retarded by the distance of half its length. The maximum disturbance and the neutralization of motion, by equally opposing forces, will occur in regular succession, and form lines of double disturbance and no disturbance; the former are indicated in the figure by the points where the circles intersect each other; the distance between points of intersection being the width of one or more waves, or by an even number of half waves. The latter — the points of no disturbance — are situated at distances from the centres, differing by the length of half a wave or by an odd number of half waves.

The interference of two systems of waves of light with each other is illustrated by Fig. 21. If two rays of light, proceeding in the direction of A A′, have each the same

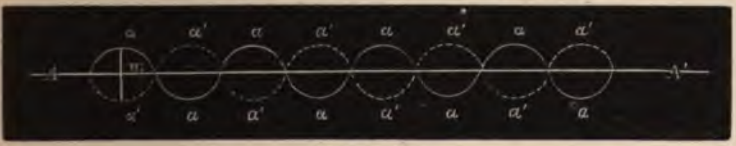


Figure 21.

intensity, each will have the same amplitude of motion. If the waves of the first ray exactly coincide with those of the second, the intensity of illumination will be increased two-fold. If one be retarded exactly the length of half a wave, then the ascending wave of one system of rays would meet

the descending wave of the other, and the two would neutralize each other; all particles on the line A A′ would cease to vibrate, and darkness would be the result. Thus, in the figure, *a a a* represents the system of waves of one ray; *a′ a′ a′*, the system of the other retarded by the length of half a wave. If the first descending wave *a* meets the ascending wave *a′*, at *m*, then the particles of ether at *m* will remain at rest, because they are acted on by two equally opposing forces.

One system of waves acted on by another system in such a manner as to augment, diminish, or destroy the oscillatory motion, is called *interference*, and if applied to waves of ether, *interference of light*. As shown above, light added to light produces darkness, when waves from two sources exactly neutralize each other. When the neutralization is not complete, a great variety of the most beautiful phenomena is produced. Each degree of retardation of the waves of one ray, in reference to those of another ray, which accompanies it, produces a different effect. Perhaps no experiment shows this more beautifully than the soap-bubble, in which one ray of light strikes the outer surface and is reflected; another ray passes through to the inner surface and is there reflected. The second ray is retarded just in proportion to the thickness of the walls of the pellicle forming the bubble, because it has to pass through the pellicle twice — first direct, second by reflection; hence, it emerges just twice the thickness of the wall of the bubble behind the first ray; at the beginning, when the liquid sphere is of small diameter, the pellicle which surrounds its contour is transparent and colorless. Gradually, as the air is blown into the interior, pressing equally all parts of the concave surface, its diameter increases at the expense of its thickness. At each moment, as the pellicle grows thinner, the emerging ray has a different degree of retardation, when compared to the first reflected ray. As the bubble commences to expand, feeble colors appear; then they become more vivid; one

series of colors are, in rapid succession, followed by other series, forming, by their mixture, a multitude of most beautifully variegated colors, changing constantly up to the moment that the bubble bursts. Each new display of colors represents a different degree of interference as the retarded light wave changes its relations to the first reflected ray. When the bubble was very small, it reflected white light; just before bursting, at the top a dark spot appears. Newton found, by experiment, a limit to the thickness of all transparent objects, below which they become invisible in reflected light, and another limit in thickness above this, beyond which they only reflect white light. In the soap-bubble, the former limit is attained when the dark spot appears; in the latter, just before the colors begin to appear. Between these two limits of maximum and minimum thickness appear all of the beautiful phenomena of variegated and changing colors. When the thickness of the pellicle exceeds $\frac{57}{1000000}$ of an inch, it reflects white light; when its thickness is reduced to $\frac{3}{8}$ of a millionth of an inch, it ceases to reflect light, and a black spot is formed.

Diffraction, or the Inflection of Light.

It was one of the arguments used by Newton against the undulation theory of light, that if it were true we could see around a corner — that shadows could not exist; now this bending round a corner does actually take place, but it is only manifest under certain conditions, because, ordinarily, the different portions of the bent or inflected waves destroy each other by interference.

In 1665, Grimaldi described, for the first time, phenomena, to which he gave the name they still preserve, the *Phenomena of Diffraction.*

Diffraction, or *Inflection of Light*, is understood to be the bending of waves of light around the edges of opaque bodies.

Grimaldi, having introduced a small beam of light, through

a minute opening, into a dark room, noticed that the shadows of narrow opaque bodies, held in the course of the light, were much larger than when the size of the beam corresponded to or had a greater diameter than the width of the opaque body. The shadows from the small bundle of rays were bordered by colored fringes, that were parallel with the sides of the opaque bodies. The fringes disappeared when the light passed through a larger hole. When the light was admitted through a very small round hole in a metal plate and received on a screen, he obtained concentric rings of colored fringes, some situated in the geometric image of the opening, others outside of these, or in the shade of the metal plate. He then made two openings very near each other, and saw two series of rings, one in part superposing the other, besides a series of dark straight lines, which disappeared when one of the holes was closed, thus showing by direct experiment that light added to light produces darkness.

Newton studied these phenomena, and endeavored in vain to explain them on the principles of the emission theory of light; it remained for Fraunhofer, Young, and Fresnel to account for them by the theory of wave motion, called by Young the *principle of interference*, the truth of which Fresnel afterwards demonstrated by his famous experiment with his two mirrors. The phenomena of diffraction is easily shown by holding a thin object, as a knife-blade, with its flat surface parallel with a screen on which a beam of sunlight falls. The shadow from the edge of the knife will be bordered by a series of different-colored fringes. If monochromatic light be employed, the fringes will be simply light and dark shades. If a thick wire be used, the fringes will be seen on both sides of the shadow. If a thin wire or a hair be substituted, the geometric shadow itself will have parallel stripes, showing that the luminous waves bend around the sides of the body. These effects are not produced if the opening in the shutter admits too large a

beam of light. If the source of light be sufficiently large, the shadows of small objects are entirely obliterated at a certain distance from the screen. For illustration, if a hair or a pin be held two or three feet from a screen which receives the full blaze of the sun, the shadow will be entirely obliterated or washed out. So, in the eye, certain minute opaque bodies, always found in the refractive media, produce no shadows on the retina when the light is admitted through the full size of the pupil. As will hereafter be shown, if the light be admitted through a small hole in a card, these minute bodies cast visible shadows on the fundus of the eye.

The phenomena of interference is one of the fundamental properties of light, but under ordinary circumstances it is not evident, owing to the causes of disturbance exactly compensating each other. If one-half of the compensating system be removed, the disturbance produced by the remaining half immediately shows itself. For illustration: if, on the surface of a highly-polished plate of steel, fine lines be traced to the number of five or six hundred to the line of measure, it then reflects a great number of divergent cones of light; these cones interfere at their edges without compensation, because corresponding rays are not reflected by the grooves which occur at regular intervals. A great variety of brilliant iridescent tints are now seen on exposing the grooved surface to the light. The varied hues of the feathers of birds, the variegated colors of the mother-of-pearl and of many shells, owe their diversified tints to their extremely thin lamina, the edges of which form a series of grooves upon their surfaces, which destroy the compensating half of the illuminating waves.

Colors of Thin Plates.— The beautifully variegated colors of thin transparent substances are dependent for their origin upon interference of light, as illustrated in the soap-bubble above alluded to. Glass blown very thin gives a great variety of beautiful tints; the iridescent colors of the wings of certain insects, the varied hues of crystals — as of mica —

when split in very thin plates, lead skimmings, the oxidation of the surfaces of plates of steel in the process of cooling, oil spread on the surface of water, etc., are examples of brilliant and variegated hues produced by interference of illuminating waves of elastic ether.

Measurement of the Waves of Light.

If two small apertures be made with a pin in a very thin metal plate, and on each of these holes monochromatic light be concentrated by strong lenses, the points of light filling these holes become independent centres of wave motion, from each of which divergent cones of light will proceed. If a screen be held parallel with the metal plate, and at such a distance that, when the bottom marginal rays of the cone from the upper luminous hole, standing perpendicular to the screen, is met by the top marginal rays of the cone proceeding from the lower point of light, the waves of the two cones will superpose each other, and there will be series of light and dark circular bands. The waves of the lower cone of light falling obliquely on the screen, while those from the upper fall on it perpendicularly, have a greater distance to pass over; consequently, when the two systems meet interference takes place.

To form the bright bands, which have double the intensity of the light from a single illuminating point, a crest of a wave of one system must coincide with the crest of a wave of the other. When the distance travelled by the two rays differs by an even number of half undulations, the two halves being equal to one entire undulation, maximum brightness ensues. When they differ by an odd number of half waves, darkness results. If one of the openings admitting the light be closed, the dark bands disappear. The measurement of the width of one of these bands gives the data for the calculation of the length of the wave of the light used in the experiment. Different kinds of light require that the oblique rays meet the perpendicular ones on the screen, at different

degrees of obliquity, according to the length of the waves belonging to each particular kind of light used. The bands are broadest in red and narrowest in violet light.

Double Refraction — Polarization.

Bartholin, a distinguished Swedish physician about the middle of the seventeenth century, in examining a crystal of Iceland spar, found that when he saw objects through it they appeared double. Twenty years later Huygens, the originator of the now almost universally adopted wave theory of light, investigated the phenomena, and gave it the name of *Double Refraction*. Phenomena of the same nature have, since that time, been studied in all their various phases, and the laws governing them elucidated and explained according to the principles of the undulatory theory of light. The rays that produce the *ordinary* image are governed by the laws of simple refraction, and this image is fixed. The *extraordinary* image executes a rotation around the first, and the rays that form it are governed by laws peculiar to themselves; the ratio of the sines of the angles of incidence, and of the angles of refraction, is not a constant quantity. In 1808, Malus, in looking through a bi-refractive prism at one of the windows of the Luxembourg Palace, at Paris, from which the solar light was reflected, discovered that, if the prism was held in a certain position, the ordinary image of the window nearly disappeared, leaving the extraordinary image; while in a position perpendicular to this the extraordinary image disappeared and the ordinary one became visible. Light thus acted upon is said to be *polarized*. This property is best studied and understood by means of the bi-refractive crystal called tourmaline, which has its molecular groupings so arranged that one of the rays is rapidly quenched, while the other is freely transmitted. It is proper to remark, that in all positions the relative intensity of the two images does not vary; the brightness of each is less than that of the luminous

object, and when the images are made to superpose, their combined brightness equals that of the object. The prism of Nicol is also used in investigating the property of polarization; this prism is made from a long parallelopiped crystal of Iceland spar, which has been sawed in two pieces by a very oblique section. The newly-cut surfaces, after being polished, are replaced in their original positions and fastened together by means of Canada balsam. When a ray of light penetrates this prism, it is divided by the first section, and the ordinary ray totally reflected at the surface of junction; the extraordinary ray passes through the second half of the crystal and emerges from its opposite face. Tourmaline produces a similar effect by largely absorbing the ordinary ray. This property of the crystal was discovered by Biot in 1815. When a prism of tourmaline is split into layers, two or three lines in thickness, parallel to its axis, then luminous objects appear through a layer as if seen through colored glass. If one layer be interposed perpendicularly between the eye and a candle, the latter will be seen equally clear and distinct in all positions of its axis, and the situation of the candle, as regards the horizon, will be unchanged. If the first lamina be fixed, and the second lamina of tourmaline be interposed between the first one and the eye, on turning the former slowly in its own plane a very curious phenomena takes place — the candle will become alternately visible and invisible at each quarter of the revolution of the layer, in passing through all degrees of brightness, from its maximum to almost total obscurity. The maximum brightness is when the axes are parallel to each other, as they were originally in the crystal; and the greatest obscurity obtains when these axes are perpendicular to one another — that is, when they cross at right angles; although two pieces of the crystal are perfectly transparent, yet, when their axes cross each other perpendicularly, scarcely any light is transmitted, and objects are invisible through them. Light is polarized by reflection as well as by refraction. When a bundle of natural

rays fall on a non-metallic mirror, as black glass, marble, obsidian, etc., it acquires the same qualities as if it had been divided by passing through a bi-refractive crystal; it is polarized. If a plate of black glass be placed on a table before an open window, in such a position as to throw into the eyes, at an angle of 35°, the reflected light from the clouds, then, without changing the position of the eyes, if a layer of tourmaline, cut parallel to its axis, be placed before them and turned in its own plane, we notice the following changes: If the axis of the tourmaline be in the vertical plane, the bright image of the clouds disappears, the reflecting surface of the glass is obscured, and its central portion becomes entirely black. When, on the contrary, its axis is horizontal, that is, parallel to the plate of glass, the obscurity entirely passes away, and the clouds are visible in their primitive brightness. This brightness gradually diminishes as the layer of tourmaline passes from the second to the first position. When the angle of incidence has another value, the image is not entirely extinguished. The angle of polarization varies with different substances: For obsidian, it is 54° 40′; for topaz, 58° 40′; for diamond, 68° 2′. As the object of these notes is only to give such information as will enable the reader to comprehend the various phenomena connected with vision, and as the laws governing double refraction and polarization belong to a special department of optics, and have no immediate connection with the optical or physiological manifestations of vision, the limits of this work permit us only very briefly to refer to this interesting subject.

PART II.

PHYSIOLOGICAL OPTICS.

PHYSICAL optics treats of the properties and laws of light.

Physiological optics is the study of such of these properties and laws as have a direct connection with the visual perceptions, through the eye, as an optical instrument.

To this optical apparatus is attached the retina — a nervous expansion — that receives impressions of light emanating from exterior bodies, which, when transmitted to the brain by the optic nerve, create sensations which make us conscious of the existence of objects situated in space.

The visual perceptions are usually treated of under three heads, viz.:

1st. The *dioptrics of the eye*, embracing the study of the course of light through the refractive media.

2d. The study of the sensations experienced from the action of light on the expansion of the optic nerve, without regard to the perception or recognition of exterior objects.

3d. The study of the interpretations of visual sensations, by which means we form definite ideas of the existence, form, and position of objects situated in space.

It will not be attempted here to minutely treat of the dioptrics of the eye; the subject is a long and complicated one, requiring a thorough knowledge of the higher mathematics for a complete comprehension of it in all its various departments. This branch will only be elucidated so far as

may be necessary to obtain a general idea of the course of rays of light in the refractive media of the eye, of the formation of images, of the size of circles of diffusion, etc., and to determine and explain the causes of errors of refraction and other defects of the eye as an optical instrument.

Anatomical Construction of the Eye.

The eye is composed of certain almost perfectly transparent refractive media; namely, the cornea, the aqueous humor, the crystalline lens enclosed in its capsule, and the vitreous humor; of the retina, a nervous expansion of the optic nerve, in which is formed the image of the object; of the choroid coat, a dark smooth cushion, on which the nervous expansion rests; of the sclerotic coat, a strong, firm, dense fibrous membrane, that retains the form of the eye, and protects the delicate internal structures from injury; of the optic nerve, which conveys to the brain the impressions made by luminous rays or waves of ether on the retina; of the iris, a curtain placed in front of the crystalline lens, forming the pupil, which contracts and dilates so as to admit the proper quantity of light into the eye; of the ciliary muscle, or muscle of accommodation, which acts so as to adjust the eye for seeing distinctly, objects placed at different distances, besides of arteries, veins, and absorbent vessels. The eyes, resting on cushions of fatty tissue, are placed in bony orbits, and are moved by external muscles — those of the two eyes acting in perfect harmony, under control of the will — that direct the visual lines to the part of the object desired to be sharply seen. The eye, as an optical instrument, is of a most perfect design, but more or less imperfectly constructed. The chief refracting surfaces are not spherical. The cornea is the vertical section of an ellipsoid with three diameters, the longest of which corresponds to the ocular axis, which passes from the apex of the cornea to the posterior scleral pole; the next in length is usually nearly transverse, and the shortest one vertical—the latter two

being perpendicular to each other, and both are perpendicular to the former. Nor are the different meridians of either of the two surfaces of the crystalline lens symmetrical, but the meridian of maximum curvature is usually horizontal and the minimum vertical. If the cornea were the vertical section of an ellipse rotated, the curvatures would be the same in all of its meridians — but this regularity is rarely, if ever, found; hence, it follows that different planes of light from a bundle of homocentric rays, after being refracted by the anterior surface of the cornea, are not directed to exactly the same point; this deviation, arising from inequalities in the degree of the curvatures of its different meridians, is known as *astigmatism* of the cornea. Similar inequalities existing in the degrees of curvatures in the different meridians of one or of both the surfaces of the crystalline lens give rise to *lenticular astigmatism;* but here, as the meridian of greatest curvature is usually horizontal, and the meridian of least curvature vertical, these positions partly correct the effects of the asymmetrical formation of the cornea. It sometimes, however, happens that the meridians of greatest and least curvatures of the crystalline lens correspond to similar meridians of the cornea; then the sum of the corresponding maximum and minimum degrees of curvatures of the different meridians constitutes the total astigmatism.

The subject of astigmatism forms a separate chapter in the Third Part of this work, but in order that the reader may satisfy himself by actual experiments, before going farther, that his own eyes are not perfectly constructed, the following simple methods of determining this fact are here given:

Most persons can easily prove the asymmetrical formations of the different meridians of curvature of the chief refracting surfaces of the eye, by drawing on a piece of paper two fine black lines, crossing each other at right angles, and holding them in front of one eye (the other being closed), in such a position that the lines correspond with the maximum and minimum meridians of curvature of

the cornea — one being vertical the other horizontal. By looking at the lines through a convex lens of ten inches focus, when the eye is accurately adjusted to see the vertical line sharply defined, the horizontal one is pale and indistinct. If the distance of the paper be changed so that the horizontal line is very black and clearly seen, the vertical one becomes pale and indistinctly defined. If a blackened card be perforated with a fine needle, and placed against a piece of frosted or milky glass, or white gauze paper, and held to the light at such a distance, the hole is seen round and sharply defined in the focus of a strong convex lens placed before the eye; then, if the card be moved a little nearer the eye, the hole becomes elongated horizontally; if carried beyond the accurately adjusted focus, the hole becomes elongated vertically. If a narrow slit, half a line or a line in width, be made in a card or metal plate, and the slit be held before the eye to correspond with the vertical meridian, horizontal lines are seen nearest to the eye. On the contrary, vertical lines are seen at a greater distance when the slit is turned to correspond with the horizontal meridian. The reason of this will be explained under the head of Astigmatism. The axes of the cornea and crystalline lens are not accurately centred; the axis of the latter cuts the cornea at the temporal side of its zenith. The plane of the equator of the lens does not rest quite parallel to the base of the cornea. The eye is not perfectly achromatic; when accurately adjusted for sharp vision, the extreme red rays fall to the outside of the fovea centralis, on less sensitive portions of the retina, but under ordinary circumstances produce no perceptible impressions. It was for a long time thought that the eye was perfectly achromatic, and such was the opinion of Euler and Newton; Young first showed the incorrectness of these views. We also find spherical aberration and a phenomenon known as fluorescence. These defects in the eye are, under ordinary circumstances, compensated for through partial psychical suppression, the senso-

rium taking cognizance only of the brighter and more perfectly formed central portion of the retinal image, so that the defects, when not of too high a degree, are unobserved, and it is only by careful experiments that they can be detected. Their existence, however, led Helmholtz to make the following remark: "Now, it is not too much to say that, if an optician wanted to sell me an instrument which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms, and giving him back his instrument."

Dioptrics of the Eye.

The interior of the eye is a dark chamber containing refractive media, through which all incident light must pass in order to reach the retina,—the expansion of the optic nerve covering the fundus and sides of the chamber,—in which is formed a small inverted image of an object looked at. That the image is real, inverted, and much smaller than the object, is easily shown by taking an eye from an animal recently killed, and carefully removing the posterior part of the sclerotic and choroid coats, leaving the retina intact; then, by placing a lighted candle in front of the eye, the miniature inverted image of the flame is easily seen shining through the retina. The image is more sharply defined if a small portion of the retina be removed, and a thin piece of glass or mica placed in the opening. The ophthalmoscope also enables us to see images formed on the retina of the human eye, by looking into it through the pupil. It was shown in the part of this work devoted to physical optics, that all actual images are formed either by convex refracting or concave reflecting surfaces. In the eye we have only to treat of refraction of light by a series of spherical, or nearly spherical surfaces, each one having a different degree of curvature, forming in the aggregate a compound lens. In ordinary dioptrical calculations, this compound lens is

regarded as having a system composed of three convex revolution surfaces, with their axes centred, that is, all resting in a single straight line. The first of these is the anterior surface of the cornea; second, the anterior surface of the crystalline lens; third, the posterior surface of the crystalline, or, we may say, the anterior surface of the vitreous humor. Owing to the fact that light passes from the air, a very rare medium, to the cornea, one of much greater density, its anterior surface, which has a radius of curvature of eight millimetres, is by far the most important of the three refracting surfaces, it alone bending parallel rays of light towards a point situated about five lines behind the retina. The posterior surface of the cornea having an index of refraction about the same as the aqueous and vitreous humors, namely, 1·3366, is not taken into consideration in dioptrical calculations. The aqueous humor, then, is regarded as extending to the anterior surface of the cornea. The combined refractive power of the two surfaces of the crystalline lens is much less than the anterior surface of the cornea, and if its structure were homogeneous, like glass or crystal, mathematical calculations prove that it would fail to bring parallel rays, after being refracted by the cornea, to a focus on the bacillar layer of the retina. Its power is increased by the peculiarity of its formation, being composed of a firm nucleus covered by numerous layers, of densities decreasing as they approach the exterior, each surface of which adds to its refractive power, and it is through the combined action of the different layers that the images of the objects are formed at the precise point necessary for distinct vision. In consequence of the laminated structure of the crystalline lens, with refractive power increasing towards the centre, its index of refraction is higher even than that of the central nucleus. Listing has placed the coefficient of refraction at 1·455. The retina, in which are formed the images of objects, is not equally impressible in all its parts. Its most sensitive portion is the yellow spot (*macula lutea*), in

the centre of which there is a small depression (*fovea centralis*). It is this part of the retina that always fixes the point of an object directly looked at, and it is immediately around the centre of this depression that the images of objects are formed when the latter are sharply seen.

It was for a long time thought that the macula lutea was situated at the posterior scleral pole — that is, the point where the long axis of the cornea falls on the fundus of the eye — a point situated about midway between the external edge of the optic disk and the inner edge of the yellow spot; but Helmholtz and others have shown that such is not the case. The macula lutea is at the outside of the posterior scleral pole, so that the visual line — that is, the line that passes from the fovea centralis through the optical centre of the eye to the point of the object fixed — forms an angle with the common axis of the refracting surfaces, assumed to correspond with the long axis of the cornea. This is shown in Fig. 22: A A, represents the long axis of the cornea prolonged outwards; V V′, the visual line passing from the yellow spot through *k*, the optical centre, to the point of an object directly looked at or *fixed*; *o* is the optic nerve

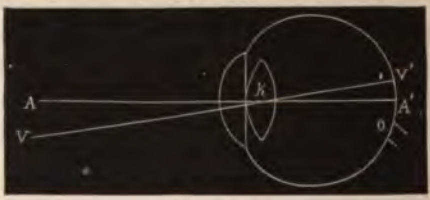


Figure 22.

entrance. The visual line cuts the cornea inside of its zenith and slightly above its horizontal meridian. In the emmetropic eye the horizontal deviation forms, with the long axis of the cornea, an angle of from two to six degrees; vertically, the deviation is from one to three degrees. The visual line passing in front of the eye a little above the horizontal meridian, the fovea centralis must be situated slightly below

this meridian. (*Helmholtz.*) As the visual line passes through a secondary axis of the compound dioptric system, it is not a straight line; in front it passes straight from the point of fixation to the anterior nodal point, then in a straight line, parallel to the first, from the posterior nodal point to the fovea centralis. The part outside of the eye is called the *line of direction;* that part within the eye, the *ray of direction.* The point of intersection of the latter with the retina gives the position of the image. As before stated, the refractive media of the eye may be regarded as a compound lens, composed of three convex refracting surfaces, with curvatures so adjusted that, in the perfectly constructed eye, parallel rays of light are united in a focus exactly on the sensitive layer of the retina. Although there are no terrestrial rays of light that are absolutely parallel, yet they are so regarded when emanating from a point twenty feet or more distant. The farthest point of distinct vision, when the eye is in a quiescent state, represents its natural refractive condition; when this is such that parallel rays of light are brought to a focus precisely on the sensitive layers of the retina, the eye is said to be *emmetropic;* the retina is situated exactly in the focus of the refractive media.

Accommodation.—If objects be brought nearer than eighteen or twenty feet distant, the rays of light falling on the cornea are divergent, and after refraction are directed to a point behind the retina; the images are blurred and indistinct. As the retina cannot move backwards to the focus for distinct near vision, a change must take place in the eye to increase its refractive power, and this change, which is known as *accommodation,* must vary just in proportion to the distance at which the object looked at is situated. In what does this change consist? The answer to this question has called forth every imaginable hypothesis. It has been attributed to an elongation of the visual axis; to an alteration in the position or form of the lens; to contraction of the pupil; to changes in the degree of convexity of the

cornea — some have even denied the existence of any active change. Kepler spent three years in endeavoring to solve the problem, and finally came to the conclusion that it was owing to an alteration in the form of the eye. Thomas Young thought that accommodation of the eye was due to an increase in the convexity of the surfaces of the lens; but as physiologists were at that time not aware of the existence of muscular fibres in the eye, the reasons which he gave for his views were not understood, "and his doctrine scarcely found a place in the long list of incorrect opinions and hazardous suggestions, which were constantly anew brought forward." (*Donders.*)

The key to unlock this hidden mystery was found by Purkinje, when he discovered faint images of the flame of a candle formed by the cornea and each of the two surfaces of the crystalline lens. Any one can see these images by placing a lighted candle so that the rays strike the surfaces at an angle of thirty degrees with the corneal axis, and fixing his eye at a similar angle on the other side; a small erect image of the flame, formed by reflection, from the anterior surface of the cornea is seen, also an erect one from the anterior surface of the lens, and a smaller inverted image formed from its posterior surface, or rather from the anterior surface of the vitreous humor. Max Langenbeck and Donders both attempted to measure the size of these images, before and after accommodation, but owing to their indistinctness and small size the results of their labors were not very satisfactory.

Cramer magnified the images from ten to twenty diameters, and thus made any changes that might occur much more manifest. He found that, in accommodation, the images reflected from the cornea underwent no change; the one from the anterior surface of the lens became smaller and approached the cornea. The small inverted image from the posterior surface of the lens did not become perceptibly smaller nor change position. Hence, the conclusion he arrived at was, that, in accommodation, the curvature of the

cornea undergoes no change; that the anterior surface of the lens becomes more convex and approaches the cornea; that the posterior surface of the lens does not move forward nor become more convex. Helmholtz, without the knowledge of Cramer's investigations, made similar experiments, and arrived at the same results, except that he found the image from the posterior surface of the lens became perceptibly smaller. By means of an instrument called the *Phacoidoscope*, the size of these images can be measured; then the radius of curvature of the surface producing each image can be calculated with mathematical accuracy. Dr. Knapp has proved that the changes in the form of the crystalline lens are sufficient to account for the most extended range of accommodation, and the same has been proved by Donders and others. Fig. 23, after Donders, shows by the curved lines the form of the lens when at rest, that is, when adjusted for infinite distance. The dotted lines indicate its form when adjusted for the nearest point of distinct vision.

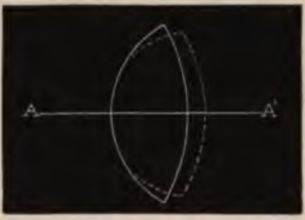


Figure 23.

Mechanism of Accommodation.

The following changes take place in the adjustment of the eye for seeing objects situated at different distances:

1st. The pupil contracts in near and dilates in distant vision.

2d. The middle of the anterior surface of the crystalline and the pupillary border of the iris move forward in accommodation for objects nearer than infinite distance.

3d. The convexity of the anterior surface of the lens increases for near and diminishes for distant vision.

4th. The inverted image, from the posterior surface of the lens, is a little smaller in near vision, indicating a slight increase in the convexity of the posterior surface of the lens.

5th. C. Voelkers and V. Hensen have proved that during accommodation the choroid coat moves forward.

These alterations in form and position are shown in Fig. 24, which represents a horizontal section of the anterior part of an eye; the left half of the figure (F) represents the

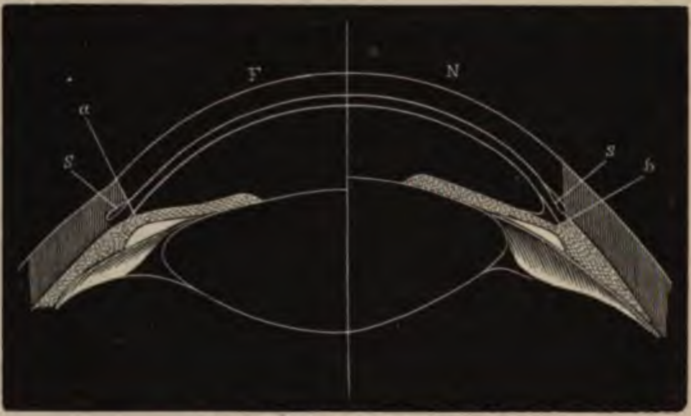


Figure 24, (after Helmholtz.)

eye at rest; the right half (N) gives the form and position of the parts when the eye is accommodated for the nearest point of distinct vision. In the eye at rest it is seen that the iris (*a*) forms a curve near Schlemm's canal (S). On the opposite side, in which the eye is accommodated for near vision, the circular fibres of the iris are contracted, diminishing the size of the pupil, with simultaneous contraction of the longitudinal fibres, straightening its periphery (*b*); the anterior chamber is lengthened and diminished in depth.

The question next arises, what produces these changes in the interior of the eye during accommodation. It was formerly thought that the iris and the external ocular muscles assisted in the adjustment of the eye for near vision, but in cases of paralysis of the latter, and in some instances which have occurred in which the former has been entirely removed, the accommodation has remained normal. Anat-

omists have discovered that what was formerly described as the ciliary ligament, contains muscular fibres, and it is now known as the *ciliary muscle*; it is definitely settled that it alone acts in increasing the convexity of the surfaces of the crystalline; hence, it is now called the *muscle of accommodation*. This knowledge is of great importance to the ophthalmic surgeon, as it throws new light on many hitherto obscure affections, formerly regarded as nervous, and which are now known to be the result of excessive muscular action —*accommodative asthenopia*—a condition easily overcome by relieving the overstrained muscle by means of convex glasses. The precise manner in which the ciliary muscle acts to produce these accommodation changes, is not yet satisfactorily determined. The muscle does not rest in contact with the equator of the lens. Most physiologists adopt the theory of Helmholtz, who thinks that the lens, which has a certain innate elasticity, is kept flattened by the zonula zinnii, through its action on the capsules; that the ciliary muscle, which is triangular, contains longitudinal and circular muscular fibres, having such attachments that when they contract the zonula is relaxed and the tension of the capsules diminished; the pressure being removed, the crystalline then assumes its naturally more convex form. Helmholtz' views are in accordance with the fact that, after death, when the pressure from the zonula ceases, the lens is found to be smaller in circumference, and its middle thicker, than when the eye is at rest during life. It is proper to add that Cramer thinks the periphery of the iris presses on the anterior surface of the crystalline near its equator, preventing its posterior surface from moving forward, thus assisting the ciliary muscle, by its action, to make the anterior surface of the lens still more convex. Our present exact knowledge of accommodation, and of the mechanism by which it is accomplished, simple as it now seems to us, has only been arrived at after an immense amount of laborious and patient research — one physiologist after another finding out and recording some new point bear-

ing on the subject, when the master minds of Cramer and Helmholtz, utilizing the recorded results of past investigators, added others, until finally they have given the whole subject the character of an exact science.

Range of Accommodation.

The measure of the distance between the farthest point of distinct vision, *r*, and the nearest point at which minute objects can be sharply seen, *p*, is called the ***range of accommodation***, which is represented by $\frac{1}{A}$. The distance of *r* from the anterior nodal point — or, it is sufficiently accurate for practical purposes to say from the optical centre of the eye — is represented by $\frac{1}{R}$; the distance of *p* from the same point, by $\frac{1}{P}$. The extent of the range of accommodation is found and expressed by the following formula, $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$. Infinite distance is represented by $\frac{1}{\infty}$. To apply the formula $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$, suppose a person with emmetropic eyes — eyes that at rest are adjusted for parallel rays (infinite distance) — sees sharply the eye of a cambric needle held four inches from the anterior nodal point. His eyes were at rest adjusted for infinite distance. To see distinctly the eye of the needle, the divergent rays falling on the cornea must, in the vitreous humor, have the same direction that parallel rays had when the eyes were looking at a distant object; hence, $\frac{1}{A}=\frac{1}{4}-\frac{1}{\infty}=\frac{1}{4}$. The amount of accommodation exercised is equal to an auxiliary lens of four inches focus placed within the eye; the ciliary muscle, by its action, increases the convexity of the crystalline sufficiently to give the latter an additional power of $\frac{1}{4}$; then, the divergent rays from the eye of the needle take the same course in the vitreous as parallel rays have when the muscle of accommodation is at rest.

This is the whole object of adjustment; for sharp vision, whatever may be the distance of the object seen, the cone of rays, having its base at the anterior surface of the cornea, must have its apex at the sensitive part of the retina, and as the retina cannot change its position, the rays forming the cone must always take the same direction in the vitreous humor as if they came from the farthest point of distinct vision. As another illustration of the formula $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$, suppose *r* be 12″ from the optical centre of the eye, and *p* be 4″ distant; then $\frac{1}{A}=\frac{1}{4}-\frac{1}{12}=\frac{1}{6}$. The ciliary muscle can adjust the eye for any point between *r* and *p*, that is on the line of accommodation; it contracts just sufficiently to make the apex of the cone of rays in the vitreous fall on the bacillar layer of the retina. At *p* its tension is at its maximum, and if the object be brought nearer, its image becomes blurred and indistinct, because the rays in the vitreous take another direction, forming a virtual focus behind the retina; consequently, no distinct image is formed on the perceptive nervous elements. For practical purposes, *r* and *p* can be ascertained by using the Test Types of Snellen, to be found at the end of this book. The farthest distance at which No. XX. can be easily and distinctly seen, gives the position of *r*, and the nearest point at which No. 1 can be read, all the letters being clearly and sharply defined, determines the position of *p*. If it be desirable to obtain the situation of the near point with greater accuracy, a wire optometer may be used, or, better still, a small point of light, which changes form the moment the eye fails to accurately accommodate for it.

The value of A is usually expressed in Paris inches. An English inch is equal to about 0·94 Paris inch, the proportion being very nearly as 16 to 17. Most of the trial glasses in use in this country are of French manufacture — Nachet's lenses being adopted as the standard. Their focal

distances may be reduced to English measurement by multiplying them by 17 and dividing the result by 16. It is important that this should be borne in mind in the adjustment of spectacles, particularly when the stronger numbers are prescribed. As the power of lenses is inversely proportional to their focal distances, F is always expressed in fractions; as, 1 : F or $\frac{1}{F}$. If the focal distance be negative, it is expressed by prefixing the sign —; thus, a convex glass of 12″ focal length, is represented by $+ \frac{1}{12}$, or, when no sign is prefixed, the fraction is understood as defining the power of a convex lens. A negative glass of, for example, 6″ focal distance, is expressed by $-\frac{1}{6}$. The signification of the following marks are: ′ foot, ″ inch, ‴ line. In neutralizing errors of refraction, the distance of the lens from the eye must be taken into consideration; for example, if it be desired to give to the refractive media an additional power of $\frac{1}{10}$, it is accomplished by placing a convex glass of $\frac{1}{10\frac{1}{2}}$ half an inch in front of the anterior nodal point. If, on the contrary, it be desirable to diminish the refractive power of the eye $\frac{1}{10}$, a lens of $-\frac{1}{9\frac{1}{2}}$, held half an inch in front of the anterior nodal point, would be the strength of the required glass. When errors of refraction are determined by trial lenses, to be accurate, the distance at which the glasses are held from the eye must be subtracted from the focal lengths of convex, and added to concave lenses.

Convergence.

All that has been previously said in reference to accommodation applies to monocular vision. We now come to treat of single vision with the two eyes (binocular vision), producing an effect as if a single eye was placed intermediate between the two, with a visual line passing from it to the point of an object sharply fixed. To accomplish this result, it is necessary that the visual lines of each eye should be directed to the same point. This act is called *convergence*,

which is effected by the external ocular muscles, those of both eyes acting in perfect harmony. When the eyes are directed to a distant object, the visual lines are parallel. If the object be nearer than twenty feet, the axes converge so as to meet at the point sharply seen; hence, the degree of convergence must vary according to the distance of the object looked at. The maximum degree is attained by holding a small object at the nearest point of distinct binocular vision. It should be mentioned, that in accommodation and convergence there is always an associated contraction of the pupils. The *line of convergence* extends from the binocular near point to the farthest point of clear vision, which, in the emmetropic eyes, reaches to an infinite distance. The visual axes can be converged so as to meet at any point on this line, and for each degree of convergence there is a corresponding amount of accommodation, and *vice versâ;* hence arises an intimate association between convergence and accommodation; but these associations are not absolute, for, with a certain fixed degree of convergence, the object can be brought a little nearer or carried a little farther from the eyes without impairing the sharpness of vision. This variation is called *relative accommodation*, which is measured by a line extending from the nearest to the farthest points of distinct vision with a fixed degree of convergence. Again, with a certain fixed amount of accommodation, the object can be slightly changed to a nearer or a more distant point without disturbing the sharpness of vision. This variation is called *relative convergence*, and is measured by a line drawn from the nearest to the farthest points of sharp vision with a fixed amount of accommodation. These relative associations only represent possible conditions; they cannot be maintained for any considerable length of time. They act in equalizing the adjustment, very much like a spring in a machine equalizes force suddenly applied. In quick and successive changes of the distance of small objects looked at, they temporarily preserve uninterrupted vision while the convergence and accommodation are becoming

accurately adjusted. To the surgeon a thorough knowledge of the intimate associations existing between accommodation and convergence is of the utmost importance, for upon it will, in a great measure, depend his success in treating many of the diseases of the eye.

The following formulas represent the range of accommodation in three different conditions of vision: 1. For vision with either eye separately, $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$. 2. For relative vision, $\frac{1}{A_1}=\frac{1}{P_1}-\frac{1}{R_1}$.* 3. For binocular, $\frac{1}{A_2}=\frac{1}{P_2}-\frac{1}{R_2}$.

For easy vision, relative convergence and relative accommodation must bear a certain proportion to each other, and these relations cannot long be disturbed without inducing irritation of the eye. In relative accommodation, that part induced by relaxation of the ciliary muscle is negative, while that caused by an increased muscular tension is positive. The positive should bear to the negative a relation of 3 : 2.

"The distinction here made already acquires practical importance, from the fact *that the accommodation can be maintained only for a distance, at which, in reference to the negative, the positive part of the relative range of accommodation is tolerably great.*" (*Donders.*)

It is to the disturbance of these normal relative associations that is to be attributed the principal cause of the pain, retino-ciliary irritation and conjunctival hyperæmia, induced by wearing improperly adjusted spectacles.

Extent of Line of Relative Convergence.

The line of relative convergence is shown in Fig. 25.

If the eyes E and E′ are accommodated for the point C

* In order to comprehend the full bearing of the intimate associations existing between accommodation and convergence, both in emmetropic and ametropic eyes, the reader should study the tables to be found in Donders' incomparable treatise on "The Anomalies of Refraction and Accommodation of the Eye."

on the common visual axis A A′, then the convergence can vary between the points F and F′. The line of F F′ repre-

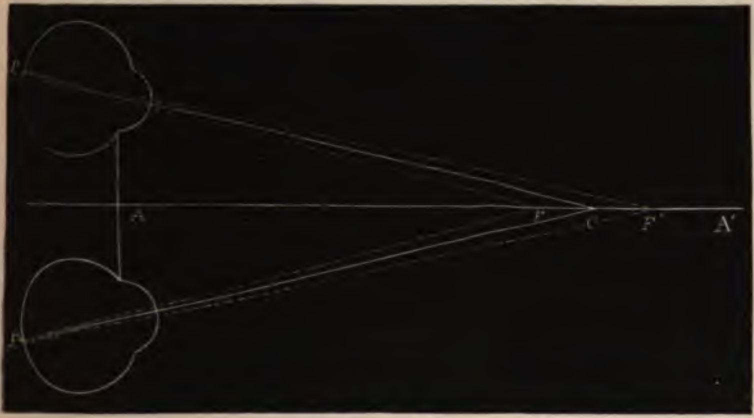


Figure 25.

sents the extent of relative convergence. The limits of the variations are indicated by the dotted lines.

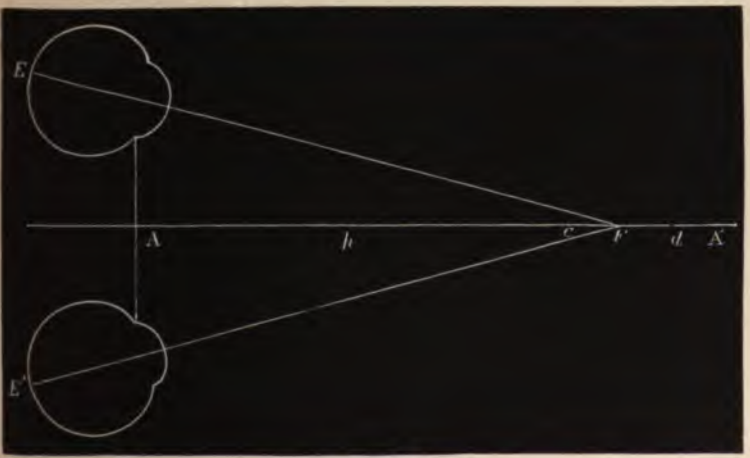


Figure 26.

Extent of the Line of Relative Accommodation.

If the eyes E E′, Fig. 26, are converged for the point F on the common visual axis A A′, then the accommodation can vary between the points *c* and *d* without disturbing the sharpness of vision. The line *c d* represents the extent of relative accommodation.

Dioptrical Calculations.

As previously stated, the refractive media of the eye may be regarded as a compound lens, composed of a single refracting surface and a bi-convex lens. The retina has a fixed position with regard to the cornea. It is the province of the mathematician to calculate the radii of curvature of each of the refracting surfaces, both at rest and in accommodation, and to accurately determine the size and actual or virtual position of the image with reference to the retina, both in emmetropia and in ametropia, the effects produced on the course of rays by changes in the position and form of the lens, and to measure the amount of these alterations; also, to determine the situation of the refracting surfaces, and of their axes with reference to each other. When we bear in mind that the refracting surfaces are not regularly curved, but ellipsoidal, and that their axes do not lie in a single straight line, we can readily see that these calculations require the exercise of the highest principles of mathematics.

Fortunately, the practical ophthalmic surgeon has the benefit of the results of the labors of great mathematicians, like Gauss, Bessel, Listing, Helmholtz, and Knapp, without himself being compelled to work out these abstruse problems.

Donders, in his most excellent treatise, says: "For the oculist, it is perhaps an advantage that I am no mathematician. I freely admit that I am not competent to follow the investigations of Gauss and of Bessel in this department, and even the study of the physiological dioptrics of Helmholtz required an effort on my part."

Cardinal Points.

The position and size of images formed by convex lenses, as well as the course of each ray of light, — falling on the refracting surfaces at very small angles of incidence, — after each refraction, are calculated from certain known fixed points. There are three pairs of these, namely, *the first and second foci*, *the first and second principal points*, and *the first and second nodal points*. The *first side* is that from which the light comes; the *second*, that to which the light passes. The first of each pair of points is on the first side; the second of each pair is on the second side. The first focus, F′, is that point from which proceed rays of light which, after refraction, become parallel. The second focus, F″, is that point in which all rays parallel on the first side unite after refraction.

On a single refracting surface, each ray, before and after refraction, is directed to the same point on that surface. In a combination of two or more refracting surfaces, it is evident that this cannot be the case. A bi-convex lens, for illustration, has within it a surface that is perpendicular to the axis, towards which each ray is directed before the first refraction. There is a second surface behind the first, — the latter being the optical image of the former,— having on it a corresponding point on the same side of the axis, to which each ray after the second refraction, traced backwards, is directed, consequently, all lines drawn between corresponding points of the two surfaces are parallel to each other and to the axis. The point on the axis where the latter is cut by the first surface is the *first principal point*. The point where the second surface cuts the axis is the *second principal point;* the distance from the first principal point to the first focus is the *principal focal distance*. The first and second *focal planes* are surfaces perpendicular to the axis, passing through the first and second foci, and are images of each other.

The first and second conjugate foci, and the first and

second principal surfaces, are shown in Fig. 27, representing the course of a ray through the crystalline lens; *a* is the first conjugate focus; *d* is the second conjugate focus. These points are images of each other. The ray *a b*, after refraction, becomes, in the lens, parallel to the axis, but before refraction is directed to the point *c'* on the first principal surface *h' h'*. The ray *a b*, after the second refraction, proceeds as *c d* to *d*; traced backwards, it appears to proceed from *c''*, a point on the second principal surface *h'' h''*; the points *c'* and *c''*

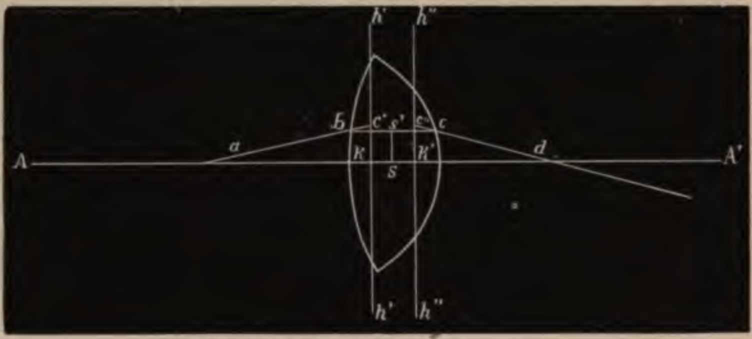


Figure 27.

are corresponding points, each equally distant from the axis A A'. The ray in the lens is parallel to the axis, and passes through *s'*; all rays passing through *s'* at one side of the lens appear to come from *c'*, and on the other side appear to come from *c''*. *k k'*, the points where the principal surfaces *h' h' h'' h''* cut the axis, are the first and second principal points, which, in a lens bounded on both sides by the same medium, correspond with the first and second nodal points. Every lens with two curved surfaces has two *nodal points*, *k' k''*, Fig. 28. A A' is the principal axis ray of the lens, and passes through unrefracted. *a b c d* is a secondary axis ray. Before the first refraction it proceeds as *a b*, and if continued in a straight line would fall on the axis at *k'*; *k'* is the first nodal point. After the second refraction, the ray proceeds as *c d*, in a line parallel to *a b*; traced backwards, it appears to proceed from the point on

the axis k''; k'' is the second nodal point. All other secondary axis rays passing through the lens are, before refraction, directed to k'; after the second refraction, they seem to proceed from k''. O, a point situated equally distant

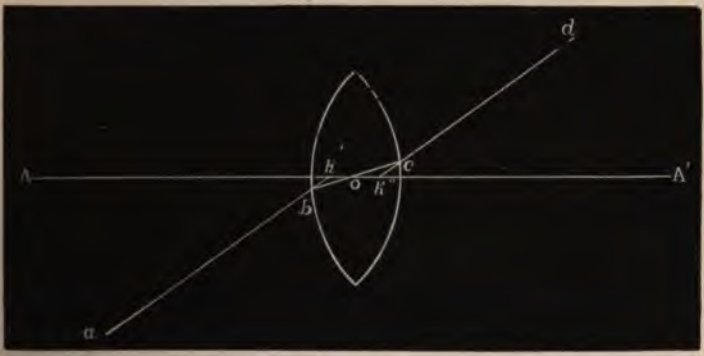


Figure 28.

between k' and k'', is the optical centre of the lens represented in the figure.

In the eye there are, including those within the crystalline, numerous refracting surfaces; but three of these are usually taken into consideration in ordinary calculations, which are regarded as revolution surfaces, namely, the anterior surface of the cornea, which is the principal one, and the anterior and posterior surfaces of the lens, all their axes being regarded as centred. Optical mathematicians have sought to find certain fixed points for this compound dioptric system, called *cardinal points*, as the basis of dioptrical calculations.

The positions of these are shown in Fig. 29, representing Listing's diagrammatic eye. F′, the anterior focus for rays parallel in the vitreous; F″, the posterior focus for rays parallel in the air. H′ H″, the two principal surfaces, cutting the axis at the two principal points, which lie in the anterior chamber. The first principal point is very near the second. k k', the two nodal points, situated near the posterior surface of the lens, also very near each other. F′ F″, the prolonged ocular

axis. V V′, the prolonged visual axis corresponding with the visual line.

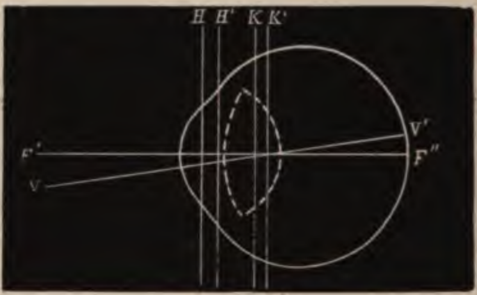


Figure 29.

The refractive coefficients are assumed as $\frac{103}{77}$ for the aqueous and vitreous humors, and $\frac{16}{11}$ for the crystalline lens.

The following established values are known as *optical constants;* they are given in millimetres, and are taken from Helmholtz's Physiological Optics.

	Accommodation for Distance.	Accommodation for Near Objects.
	Millimetres.	*Millimetres.*
Radius of curvature of the cornea	8·0	8·0
Radius of curvature of the anterior surface of the crystalline	10·0	6·0
Radius of curvature of the posterior surface of the crystalline	6·0	5·5
Position of the anterior surface of the crystalline	3·6	3·2
Position of the posterior surface of the crystalline	7·2	7·2
CALCULATED.		
Anterior focal distance of the cornea	23·692	23·692
Posterior focal distance of the cornea	31·692	31·692
Focal distance of the crystalline	43·707	33·785
Distance of the anterior principal point of the crystalline from its anterior surface	2·1073	1·9745
Distance of the posterior principal point of the crystalline from its posterior surface	1·2644	1·8100
Distance of two principal points of crystalline	0·2283	0·2155
Posterior focal distance of the eye	19·875	17·756
Anterior focal distance of the eye	14·858	13·274
Place of the anterior focus	12·918	11·241
Place of the first principal point	1·9403	2·0330
Place of the second principal point	2·3563	2·4919
Place of the first nodal point	6·957	6·515
Place of the second nodal point	7·573	6·974
Place of the posterior focus	22·231	20·248

The study of the dioptrical calculations of Listing and Helmholtz, and even of the simplified system of Donders, is too difficult for many of the readers for whom this work is intended, and is of practical importance only to the ophthalmic surgeon. For many calculations the compound dioptric system may be simplified to what is called the "*reduced system.*" Donders says: "Following Listing's example, we may go a step further in the simplification: it is, in fact, allowable to reduce the compound dioptric system of the eye to a single refracting surface, bounded anteriorly by air, posteriorly by aqueous or vitreous humor, and this reduced eye, where the greatest accuracy is not required, may be made the basis of a number of considerations and calculations. With this simplification we can, with the greatest ease, form a satisfactory idea of the magnitude of the retinal images, of the position of the conjugate foci, of the extent of the circles of diffusion in imperfect accommodation, in astigmatism, &c., and of numerous other points." Fig. 30 represents the reduced eye having but a single refracting surface, with a radius of curvature of 5 millimetres. ϕ' the position of the anterior focus; ϕ'' the posterior; h, the principal point; k, the nodal point or optical centre where all the secondary axes cross each other.

Figure 30.

$h\ \phi' = F'$, the anterior focal distance $= 15$ *mm.*

$h\ \phi'' = F''$, the posterior " " $= 20$ "

The coefficient of refraction $\frac{n'}{n} = \frac{4'}{3}$ as being $= F'' : F' = 20 : 15$.

Those who desire to study the mathematics appertaining to the compound, or the reduced, dioptric system, should consult Helmholtz's Physiologische Optik, and Donders on the Anomalies of Refraction and Accommodation. As Helmholtz's work is in German, and has not been translated

into English, and as the English (Sydenham) edition of Donders' treatise is now exhausted, consequently, difficult to obtain, and may be inaccessible to many of our readers, we take from Donders' work his calculations applicable to a single refracting surface.

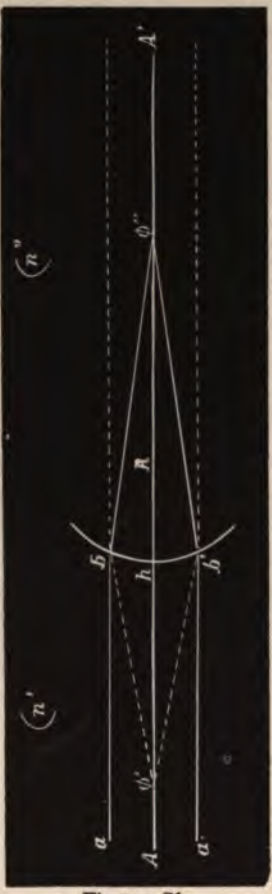


Figure 31.

(*From Donders.*)

Refraction by a Spherical Surface.

Cardinal Points.

In Fig. 31, let k be the central point of the spherical surface h, on which, parallel to the axis A A′, rays of light fall, a b and a' b', coming from the medium with index n', and passing into medium with index n''. If n'' be greater than n', the parallel rays unite in the axis nearly in a point, the posterior focal point ϕ''. The distance $h\,\phi'' =$ F″, that is, the posterior focal distance is found by the well-known formula,

$$F'' = \frac{n''\,p}{n''-n'} \quad \ldots \; 1\,a,$$ wherein the radius of the surface of curvature is $= h\,k$.

If on the same refracting surface, but in the direction from A′ to A, rays fall which, in the medium with index n'', run parallel to the axis (they are in the figure represented by dots), these also unite nearly in a point in the axis, the anterior focal point ϕ'. The distance $h\,\phi' =$ F′, called the anterior focal distance, is found by the formula,

$$F' = \frac{n'\,p}{n''-n'} \quad \ldots \; 1\,b.$$

The formulas 1 a and 1 b obtain only for rays which run close to the axis. As such they are deducible in a simple mode.

In Fig. 32, a b is the incident ray; b the point of incidence;
k b ν the normal on the spherical surface at the point of incidence;
b ϕ'' the refracted ray, bent towards the normal b k;

$a\ b\ v$ is the angle of incidence, $a = b\ k\ h$, and thus corresponding to arc $h\ b$;

Figure 32.

$\phi''\ b\ k$ is the angle of refraction β, and if we draw $d\ k$ parallel to $b\ \phi''$, we have the angle $b\ k\ d$ corresponding to the arc $d\ b$:

$h\ k\ d$ is the angle of deviation, $y = a - \beta$.

The relation of each of the focal distances $h\ \phi'' = F''$ and $h\ \phi' = F'$, to the radius $h\ k = p$ is now to be found.

For small segments $h\ k\ d$ and $h\ \phi''\ b$ may be regarded as rectilineal triangles. They are in this case uniform and rectangular in h. Consequently

$$k\ h : \phi''\ h = \text{arc}\ h\ d : \text{arc}\ h\ b.$$
$$p : F'' = a - \beta : a.$$

For small arcs we may substitute the sines, and thus alter the formula into

$$F'' : p = \sin a : \sin a - \sin \beta.$$

Then the law of refraction is, as experience teaches, the following:—

$$n' \sin a = n'' \sin \beta.$$

Consequently, if we substitute the value of $\sin a$ in our proportion,

$$F'' : p = n'' : n'' - n'$$
$$F' = \frac{p\ n''}{n'' - n'}.$$

The relation of F' to F'' is, moreover, easily found. The ray $a'\ b$, running parallel to the axis in n'', is bent from the normal $b\ v$, and proceeds as $b\ \phi'$. By this deflection the angle of refraction $v\ b\ \phi' = \beta'$ becomes greater than the angle of incidence $a' = a$. However, the law of refraction must here also find its application, and thus the proportions remain the same, as immediately appears by considering $\phi'\ b$ as the incident, and $b\ a'$ as the refracted ray. There is a general law, of which we shall hereafter often make use; it is this: if a ray, proceeding from a point, passes through an optical system, in order to come to a second point, a ray from this second point will, *vice versâ*, be able to reach the first point, only by following precisely the same

route in an opposite direction. As the angles of deviation are proportional to the angles of refraction, we here obtain

$$b \phi' h : b \phi'' h = v b a : \phi'' b k,$$

that is, for small angles,

$$y' : y = a : \beta = n'' : n'.$$

Now as $F' : F'' = y' : y'$,

we have $F' = F'' \frac{n'}{n''} \ldots\ldots$ 1 *c.*

But, $F'' = \frac{p\, n''}{n'' - n'}$,

therefore, $F' = \frac{p\, n'}{n'' - n'}$.

Moreover, $F'' - F' = p \frac{n'' - n'}{n'' - n} = p$

$$F'' = F' + p \ldots\ldots\ldots \quad 1\, d.$$

If we regard n' as a unity, we obtain n'', the symbol of the relative index of refraction with respect to the air, and we obtain

$$F' \frac{p}{n'' - 1}$$

$$F'' \frac{p\, n''}{n'' - 1}.$$

Thus we recognize *four cardinal points* in the axis:—

ϕ', the anterior focus.

h, the point of section of the spherical surface with the axis.

k, the centre of curvature.

ϕ'', the posterior focus.

From the distances between these points flow the following values:—

$h \phi'$, the anterior focal distance F'.

$h \phi''$, the posterior focal distance F''.

We further distinguish —

$k \phi'$ as G', $k \phi''$ as G'',

then: $G' = F' + p = F'' \ldots.$ 2 *b*

$G'' = F'' - p = F' \ldots.$ 2 *a*

$G' = G'' + p \quad \ldots.$ 2 *d*

$\frac{G''}{G'} = \frac{F'}{F''} = \frac{n'}{n''} \ldots\ldots$ 2 *c*

Conjugate Foci and Relation between Magnitude B of the Object, and Magnitude β of the Image.

Having ascertained these values, we can, by a simple construction, find both the conjugate *foci* and the relation between the magnitude of the object and that of the image $B : \beta$.

Let i', Fig. 33, be a given point of light; if we wish to find its image: From i' proceeds: 1. the ray $i' \, k \, j'$, which, being directed to k, coincides with the normal of the refracting surface, and passes through unrefracted; 2. the ray $i' \, b$, which, as being parallel to the axis, after refraction passes through ϕ''. *All* the rays proceeding from i' unite in one point. Consequently, where two rays, proceeding from i', cut one another, is its conjugate focus. This point is j', and j' is therefore the image of the point of light i'.

The points of an object, which lie in a line perpendicular to the axis, are also in the image situated in a line perpendicular to the axis. Consequently, the image of the point of light i is in j. The object $i \, i' = \mathrm{B}$ will, therefore, have an image β, the magnitude of which is $j \, j'$.

It is of importance to prove this last proposition. From the point of light i' (Fig. 33), proceed, as we saw, two rays, the direction of which we know; the ray $i' \, j'$, and the ray $i' \, b \, \phi''$, in whose point of intersection lies j', the image of i'. To find this, we draw the perpendicular $s \, d$ at a point of the axis arbitrarily taken, provided only that the perpendicular cut the two rays $i' \, j'$ and $b \, j'$. We thus obtain two pairs of similar triangles, $\phi'' \, h \, b$ and $\phi'' \, s \, c$, and $k \, i \, i'$ and $k \, s \, d$; moreover, $h \, b$ is $= i \, i'$. The said triangles give us now the subjoined proportions:—

$$\phi'' \, h : h \, b = \phi'' \, s : s \, c \text{ and}$$
$$k \, i : h \, b = k \, s : s \, d,$$

consequently,

$$s \, c = \frac{h \, b \times \phi'' \, s}{\phi'' \, h} \text{ and } s \, d = \frac{h \, b \times k \, s}{k \, i}$$

Figure 33.

we see that $s \, c$ will be $= s \, d$, if

$$\frac{\phi'' \, s}{\phi'' \, h} = \frac{k \, s}{k \, i}.$$

This is evidently the case, if the point s is removed towards j. The situation of the point j is therefore determined by

$$\phi'' \, j : \phi'' \, h = k \, j : k \, i.$$

On the perpendicular from j, we have $s\,c = s\,d$, and here, therefore, the ray passing through k, crosses that passing through ϕ''. This is the case for every value of $h\,b$ or $i\,i'$, which term does not occur in the proportion. Every point of the perpendicular $j\,j'$, therefore, has its image on the perpendicular $i\,i'$. Q. E. D.

In the above figure,

$$h\,\phi'' = F'' = G'$$
$$k\,\phi'' = G'' = F'.$$

If we now call the conjugate focal distances, measured from h, $h\,i = f'$ and $h\,j = f''$, and, measured from k, $k\,i = g'$ and $k\,j = g''$, we obtain, in place of,

$$\phi''\,j : \phi''\,h = k\,j : h\,i, \ldots\ldots\ldots \text{A}$$

the proportion

$$g'' - G'' : G' = g'' : g',$$

and hence directly

$$g' = \frac{G'\,g''}{g'' - G''} \cdots\cdots (3\,a$$

or,

$$g'\,g'' - g'\,G'' = G'\,g''$$
$$g'\,g'' - G'\,g'' = g'\,G''$$
$$g''\,(g' - G') = g'\,G''$$
$$g'' = \frac{G''\,g'}{g' - G'} \cdots\cdots 3)\,b.$$

In place of the proportion A we may equally write

$$f'' - F'' : F'' = F' + f'' - F'' : f' + F'' - F'.$$

Hence follows,

$$f'\,f'' - f'\,F'' + f''\,F'' - F''\,F'' - f''\,F' + F'\,F'' = f''\,F'' - F''\,F'' + F'\,F''\,f'\,f'' - f'\,F'' - f''\,F' = 0$$
$$f'\,(f'' - F'') = f''\,F'\,f''\,(f' - F') = f'\,F''$$
$$f' = \frac{f''\,F'}{f'' - F''} \cdots\cdots 3\,c) \qquad f'' = \frac{f'\,F''}{f' - F'}\,3\,d).$$

In the same figure we find still two pairs of similar triangles,

$$i\,i'\,k \text{ and } k\,j'\,j$$

and

$$h\,b\,\phi'' \text{ and } \phi''\,j\,j'.$$

Hence we have two proportions, expressing the relation between the magnitudes of object and image, namely,

$$j'\,j : i\,i' = k\,j : k\,i \text{ or } \beta : \text{B} = g'' : g' \ldots\ldots (4\,a$$

and

$$j'\,j : i\,i' = \phi''\,j : \phi''\,h \text{ or } \beta : \text{B} = f'' - F'' : F'' \ldots\ldots (4\,b.$$

Application to the Eye.

Donders adds: "All that has been brought forward is applicable to the refraction of the rays through the cornea. If, therefore, the crystalline lens be absent (aphakia), no other formulas than those above given need be used. The principal point lies on the anterior surface of the cornea; the nodal point, 8 *mm.* behind its apex. The radius of the cornea being 8 *mm.* (compare 1 *a* and 1 *b*), we find

$$F'' = \frac{8 \times 1{\cdot}3366}{1{\cdot}3366 - 1} = \frac{10{\cdot}6928}{0{\cdot}3366} = 31{\cdot}692 \text{ millimetres.}$$

$$F' = \frac{8}{1{\cdot}3366 - 1} = \frac{8}{03366} = 23{\cdot}692 \text{ millimetres.}$$

Herewith are also given $G' = F''$ and $G'' = F'$ (compare 2 *a* and 2 *d*)."

Spectacles and their Uses.

We have heretofore treated of the emmetropic eye with normal range of accommodation. Emmetropia, as previously explained, is understood as that condition of the eyes at rest, in which the sensitive layers of the retina are situated just in the focus of parallel rays. *Ametropia* is used in contradistinction to emmetropia. In the former condition the retina is either too near or too far from the anterior surface of the cornea; if parallel rays, after being refracted, have their course in the vitreous humor directed to a point behind the retina, no distinct image will be formed in the latter. This condition is called *hypermetropia.* Again, if the retina be situated beyond the focus of parallel rays (*myopia*), they overcross in the vitreous and fall on the retina in diffusion circles. There may be a deficiency in the powers of accommodation; the ciliary muscle may not adjust the eye for near vision of small objects (*presbyopia*). There may be such a degree of asymmetry between the different meridians of the refracting surfaces as to disturb the sharpness of vision (*astigmatism*). The eyes may not have

the visual lines directed to the same point of an object, causing diplopia or double vision. All of these defects may be corrected by placing before the eyes suitable glasses. The ametropic eye may be rendered emmetropic, deficiencies in the power of accommodation remedied, and diplopia prevented.

Convex Spectacles are made of bi-convex or of positive meniscus lenses; they move the images forward, and supply deficiencies of accommodation; they bend divergent rays that would otherwise impinge on the iris, so that they enter the pupil, thus increasing the number falling on the retina, adding brightness to the images; if sufficiently strong, they magnify the object.

Concave Spectacles are made either of bi-concave lenses or of lenses having the form of the negative meniscus; they cause images to be formed farther backwards by rendering parallel rays divergent before they impinge on the cornea, or, if already divergent, they increase the divergency; hence, they are used in myopia to increase the distance of the far point of distinct vision, and to allow small objects to be held farther from the eyes and still be sharply seen.

Periscopic Spectacles.— This term was applied by Wollaston to spectacles made from convexo-concave or concavo-convex lenses, because, by this form of glasses, the images are less disturbed in oblique vision, and the eyes can more freely move around, behind the glasses, and thus obtain a clearer view of objects situated obliquely in the field of vision, without changing the position of the head. Periscopic spectacles are in very general use, but it is questionable if preference should not be given to bi-convex and bi-concave glasses.

Donders says: "However, we can also see satisfactorily in an oblique direction through bi-convex and bi-concave glasses, provided they are not too strong; and if high numbers are required, the periscopic have again the disadvantage of greater weight. Were it only for this reason, the latter do not unconditionally deserve the preference. When we

add that, under some circumstances, the periscopic glasses are more liable to produce disturbance by reflection on the concave surface turned towards the eye, and that they are, moreover, somewhat more expensive, we shall not be surprised that they have not wholly supplanted the bi-convex and bi-concave glasses."

Glasses à Double Foyer.— In certain conditions of the eyes, glasses of different foci are necessary for distant and near vision. In absolute hypermetropia there is no distinct vision without convex glasses; those that suit for far vision are not sufficiently strong for reading, writing, etc.; hence, the necessity of frequently changing them for those stronger or weaker, according to the nature of the occupation in which the eyes are used. Other persons, slightly near-sighted, but with greatly diminished range of accommodation, may require concave glasses for distant vision and convex for seeing small objects. To obviate the necessity and annoyance of frequently removing one pair of spectacles and substituting another pair, Franklin, who was himself slightly myopic, with deficient accommodative powers, and required concave glasses for distant vision and convex for reading, had spectacles constructed with glasses of double focus; hence, those made on that principle are called "Franklin glasses." The upper halves are ground to have foci suited for distant vision; the lower for reading, etc. They should be placed before the eyes in such a position that, by looking upwards, they are properly adjusted for far vision, and, by looking downwards, for writing or fine work. Opticians sometimes construct Franklin glasses by dividing spherical lenses of different foci in halves, the line of separation passing through the axes of the spherical surfaces, and then placing the halves of lenses of different foci together. Persons needing glasses with double focus should have the errors of refraction accurately determined, and the optician should be very careful to grind the spherical surfaces strictly in accordance with the measurements given him.

Spectacles with Positive or Negative Cylindrical Glasses.— Cylindrical lenses correspond in form to the longitudinal section of a cylinder — the positive to the outer surface, the negative to the inner surface of a hollow cylinder; their axes are the same as glass with parallel surfaces, and do not refract light at all; the meridian of greatest curvature is perpendicular to the axis. They are used in astigmatism to equalize refraction in the different meridian planes, so that all rays from a homocentric bundle may be directed towards the same point.

Prismatic Spectacles. — It has been previously explained, that in binocular vision the visual lines of each eye must meet at the common point of fixation, so that the images may be formed on identical parts of the two retinas — on the yellow spots. To accomplish this result, the internal recti muscles of the eyes are brought into action, and they ordinarily move in such perfect harmony that the moment we desire to see any particular point of an object, both visual lines are accurately directed to it, and there is single vision with two retinal images. If, however, one muscle — for example, the internal rectus of the right eye — be deficient in power, the eye will not converge sufficiently; the image belonging to it will be formed at the temporal side of the yellow spot, and there will be two objects perceived — the false to the left of the true one. This is shown in Fig. 35. Let *a* be the flame of a candle, three feet distant from the eyes, *y* the yellow spot of the left eye, *y′* the same of the right eye. In order that *a* may be seen single with both eyes, the visual lines must pass from *y* and *y′* direct to *a*. But in

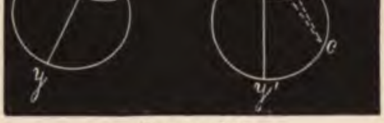


Figure 35.

the figure the right eye is not sufficiently converged or turned inwards, and the image is formed at *c*, to the temporal side of the fovea centralis, and is projected inwards towards *e*. (*Crossed diplopia.*) To bring the false image to such a position on the retina that it will fuse with the true one, and but a single sensation be produced, the internal rectus must turn the cornea inwards until the yellow spot y', which moves in the opposite direction, is at *c*; then the two images, being formed on identical parts of the two retinas, are fused, and but a single flame is seen. In case of insufficiency of the internal rectus muscle, it is unable to converge the right eye sufficiently to produce this effect, and recourse must be had to a prism with its base inwards, by which means the image is brought to the yellow spot, without the yellow spot moving outwards. The action of the prism P P′ is shown in the figure. y' is fixed and cannot move outwards. The prism bends the ray *a c* inwards, so that it falls on y'; both images are now formed on identical parts of the two retinas, and but a single flame is seen. If the right eye turn too far inwards, the false image is to the right of the true one (*homonymous*). This may result from excessive action of the internal, or insufficiency of the external rectus; here the base of the prism should be turned outwards. The angle of the prism must correspond with the effect desired to be produced. Prisms may be adapted to one or both eyes, according to the requirements of the case.

Protecting Spectacles. — There are two varieties of these: First, colorless plane glasses, used for protecting the eye from mechanical injury by dust, pieces of coal, stone, metal, etc. Second, colored plane glasses, worn to protect the eyes from the influence of too strong a light. They are usually made from green, blue, or London smoke gray glass. Green glasses are not suited for the purpose; for while reflected green is agreeable to the eyes, transmitted green is injurious, as the strong dark green, which approaches a yellow, transmitted in a bright light, increases rather than diminishes irritation. Blue glass spectacles are preferable to green, and

in certain conditions of morbid sensibility of the retina to light, they are peculiarly grateful and pleasant; in such cases they may be prescribed. But, generally, deep blue glasses pain the eye in bright light, and pale blue glasses weaken the light too little to afford effective protection.

London Smoke Glass Spectacles. — Sunlight, reflected by objects in their different colors, is the natural stimulant to the special nervous elements of the retina; hence, glasses that exclude in equal proportions each color of the solar spectrum, transmit a softened light without shutting out entirely any particular color. This result is obtained by gray glasses — called neutral, or London smoke, — and should ordinarily be preferred to green or blue. When protecting spectacles are required for persons wearing spherical glasses, it is better to attach to one of the spherical surfaces a colored plane glass, by means of Canada balsam. If convex or concave lenses are made of colored glass, the shade is unequally distributed over the field of vision — the thickest part of the glass gives the darkest hue, and the plane surfaces of objects appear unequally illuminated; hence, colored glass is a material unsuited for spectacles requiring spherical or cylindrical surfaces. Ordinary colored glass spectacles only ward off the light in front of the eyes, while they permit strong light to enter obliquely, thus creating a marked contrast of light and shade, very hurtful to the visual organs. This should be prevented by having side-glasses of the same color, or a shade of some dark colored substance, to surround the eyes and ward off strong oblique light. Wire gauze answers this purpose very well, for while it shuts out the strong oblique light, it at the same time allows a free circulation of air around the eye, permits the exhalations from the mucous membrane to escape, and prevents the eyes from being bathed in their own vapors. "Lately, the so-called muscle spectacles, that is, spectacles formed like watch glasses, are much in fashion. Their convexity allows of a very considerable approach of the edges to the orbital

border, and hence furnishes a more efficient diminution of the lateral illumination than plane spectacles do. Since, however, the radius of the posterior concave surface is always smaller than the anterior convex one, these spectacles become weak concave lenses, and are as a rule, therefore, very annoying to far-sighted and hypermetropic eyes." (*Stellwag.*) Protecting spectacles should not be worn in-doors unless to shield the eyes from strong artificial light. If the ordinary light of the chamber be too bright, it is better to darken the room. If very dark glasses be habitually worn, as they weaken the illumination, the eyes are strained to get a distinct view of objects; they become accustomed to a weaker light, and on going out into the bright reflected sunlight of the open air, the contrast is so strong that a dazzling, painful sensation is produced, thus neutralizing the results desired to be obtained. To protect the eyes from the injurious effects of artificial light in reading, writing, etc., it is preferable to substitute lamp-shades for protective spectacles; the back should be turned towards the light, so as to permit the illumination to fall on the book, and not on the eyes. When gray spectacles are prescribed, they should be selected of a clear gray color. Those having a tinge of yellowish or brownish gray should be rejected, and this can easily be determined by placing them over a sheet of white paper, when objectionable tints are at once detected.

Direct Influence of Glasses with Spherical Surfaces on Vision.—As the spherical surfaces that may be required to neutralize errors of refraction cannot be placed within the organs of vision, it becomes necessary to hold them before the eyes at a certain distance from the cornea. They then become integral parts of the compound dioptric systems; but as the glasses remain stationary, while the eyes move freely behind them, it is seldom that the axes of the additional spherical surfaces are in a line with the visual axes; deviations that exert a marked influence on vision. Donders gives the following changes as the immediate consequences of placing positive or negative glasses before the eyes:

"1°. The greatest and least distances of distinct vision, P and R, undergo a modification.

"2°. The range of accommodation is altered.

"3°. The region of accommodation changes in position and extent.

"4°. The magnitude of the retinal images does not continue the same.

"5°. The determination of the distance, magnitude, and form of objects undergoes a change.

"6°. Stereoscopic vision with the two eyes suffers some modification."

Spectacle Frames.

The ingenuity of mechanical opticians has been taxed to devise means to hold glasses properly before the eyes. They are usually placed in round, oval, oblong, or octagon groove

ELASTIC STEEL SPECTACLES.

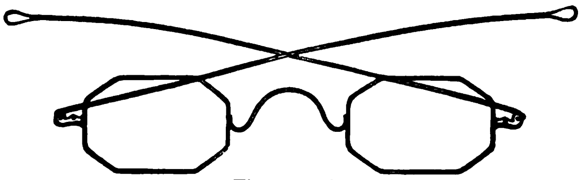


Figure 36.

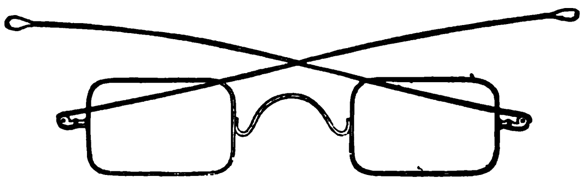


Figure 37.

rings, and, in what are called spectacles, the rings are connected by a bridge of wire that rests on the nose. At the outer sides of the rings, attached by a joint, are placed wings, that rest on the sides of the head above the ears. The accompanying figures represent some of the forms of glasses

and spectacle frames to be found in the stock kept by opticians and dealers in spectacles.*

Fig. 38 illustrates what is called turn-pin temples; the wings are jointed, and the end pieces turn down behind the ears, giving the glasses a firmer support. This form is particularly adapted for cylindrical lenses that require to be

TURN-PIN TEMPLES.

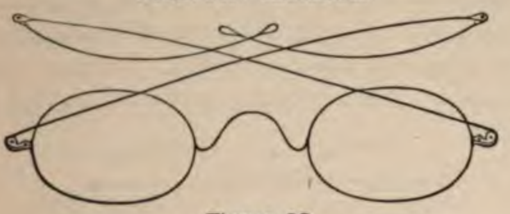


Figure 38.

PULPIT SPECTACLES.

Figure 39.

fixed in a certain unchangeable position; also, for strong, positive, and negative glasses, that, owing to their weight, are liable to be displaced by sudden jars, quick motions of the head, etc.

* These cuts are taken from the catalogue of James W. Queen & Co., Opticians, 924 Chestnut Street, Philadelphia, and 601 Broadway, New York. For the benefit of persons living at a distance from metropolitan cities, and where the assortment of glasses of different foci, kept by local dealers, is limited (particularly the weaker numbers, as $\frac{1}{60}$, $\frac{1}{72}$, $\frac{1}{84}$), I would say that all varieties of spectacles recommended in this work may be obtained from this house, among others, through the mails or otherwise. Many forms of spherico-cylindrical and spherico-prismatic glasses are not kept in the trade, and consequently must be ground according to measurements given by the ophthalmic surgeon. These may also be obtained of this establishment.

Fig. 40 represents what are called hook sides. The frames are very light, and have not sufficient strength of spring to hold the glasses in position; the curved parts of the wings rest behind the ears and give support to the frames. They are generally selected by young persons for whom spectacles are prescribed, and answer very well for the weaker numbers, but they have not sufficient strength for glasses of short focal distances. For public speakers and persons who are presbyopic, the form of glass represented in Fig. 39 is particularly recommended. They are known as *pulpit spectacles.* When wearing them, in looking up, the

Figure 40.

EYE PROTECTORS.

Figure 41.

view is unobstructed, but in turning the eyes downwards, print, writing, etc., is sharply seen, thus obviating the necessity of frequently applying and removing the glasses.

The material of which spectacle frames are made should be as light and as elastic as possible; but, at the same time, have the proper degree of strength; blue steel fulfils both of these requirements better than anything else, and is there-

fore preferable to gold or silver, besides being much cheaper than the former metal.

WIRE GAUZE EYE PROTECTORS.

Figure 42.

Adjustment of Spectacles.— In placing glasses before the eyes, they should be so adjusted as to be parallel to the planes of the pupils, and their axes should correspond, as nearly as possible, with the visual lines. For near vision, the former object is accomplished by bending the bridge so as to give the proper inclination to the spherical surfaces; the latter by modifying the length and vertical curvature of the bridge to suit each individual case. Eyes differ greatly in their reciprocal distance, and there is even a greater individual difference in the height of the nasal bones. The ophthalmic surgeon has not done enough when he has prescribed the proper focal length of glasses; he should see that the frames are so constructed that the spherical surfaces are suitably centred. When glasses are worn for seeing at a distance, the visual lines being parallel, the connecting bridge should be longer than when spectacles are worn for near vision. If the same glasses are used for seeing both near and distant objects, they should be so centred that their axes lie at an intermediate point between parallel visual lines and those of maximum convergence. For seeing distant objects, the glasses should be set high, and this requires the vertical curvature of the connecting bridge to be changed according to the height of the nasal bones. To see near objects, the glasses should be set low, and as in reading, writing, and doing fine work, etc., the eyes are turned downwards, the lower edges of the glasses should be inclined

backwards so as to bring their surfaces parallel to the planes of the pupils.

Eye-Glasses.

In the form of spectacles known to opticians as *eye-glasses*, the rims surrounding the lenses are connected by means of a steel spring, as shown in the accompanying figures, which

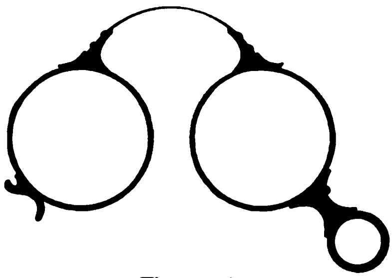


Figure 43.

represent some of the forms in general use. They are held in position by the spring, which presses the borders of the rims against the sides of the nose. They are very easily and quickly applied, and serve their purposes excellently well when used only for a short time, but are easily displaced,

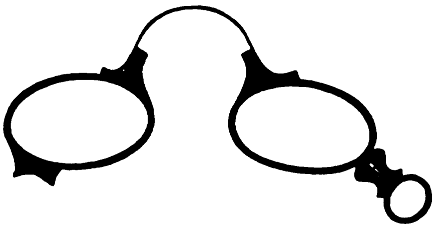


Figure 44.

and if long worn, the pressure on the integuments is liable to cause pain and irritation; hence, for constant use spectacles are preferable. It is by no means a matter of taste or fancy which form of eye-glasses is selected. They require to be centred with the same care as spectacles. If the

reciprocal distance of the eyes is small, and the width of the nasal processes slight, small round glasses, as represented in Fig. 43, should be selected. If the eyes, with the same breadth of nasal processes, are farther apart, Fig. 44 shows the proper form to suit the case. For narrow nasal processes, with widely separated eyes, Fig. 45 shows the form that may be required, and it is sometimes necessary to com-

Figure 45.

Figure 46.

bine this form with glasses of large circumference, in order that their axes may be sufficiently separated to correspond with parallel visual lines. From the above it will be seen that it is not sufficiently explicit to prescribe eye-glasses of a certain focal length — the form adapted to each particular case should be specified. Gold is too heavy a metal for the frames of eye-glasses; owing to its greater weight, the connecting spring requires to be stronger, and an increased pressure on the sides of the nose is necessary to hold the glasses in position.

Selection of Spectacles. — In order that spherical glasses may fulfil the purposes for which they are prescribed, it is of the utmost importance that they should be carefully constructed; the spherical surfaces should be accurately ground and free from all imperfections; each glass should exactly correspond in focal distance. As "the laborer is worthy of his hire," careful construction is inconsistent with great

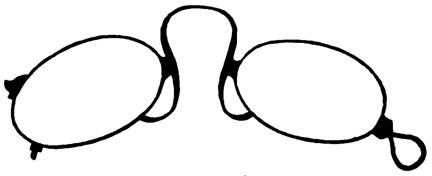


Figure 47.

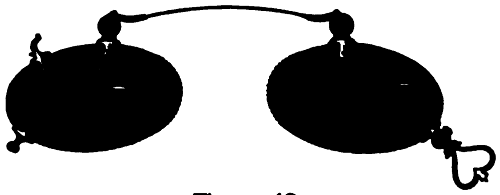


Figure 48.

cheapness; hence, very cheap spectacles should be avoided; they are often made of defective lenses, and consequently are sold at reduced prices.*

The materials of which spectacle-lenses are made are crown- and flint-glass and rock-crystal; the latter familiarly known as "pebble." For weak spherical glasses it is almost a matter of indifference of which material they are made; but for high numbers, *crown-glass* should have the preference. Flint-glass and rock-crystal are harder, consequently not so easily scratched, but they disperse light much more in proportion

* For those who cannot conveniently have the errors of refraction accurately determined by a skilled ophthalmic surgeon, instructions are given, at the end of this book, by means of which they can, with tolerable accuracy, select the strength and kind of glasses needed. These instructions will also be useful to jewellers, and other venders of spectacles.

to their refractive power than the softer crown-glass. Donders says: "Flint-glass, and especially rock-crystal, are harder and not so easily scratched. This is particularly a recommendation in the case of convex glasses, which are so much more liable to be scratched. Against the advantage just mentioned as being possessed by flint-glass and crystal, must be set down the disadvantage of greater power of dispersion. Hence it would appear that for *strong glasses* the preference ought to be given to *crown-glass*. This is especially true of concave glasses, and as to convex glasses of crown-glass, their low price makes it easy, if they are scratched, to replace them with others." He further adds: "The nature of the material of which the glasses are prepared can be best ascertained by determining the coefficient of light; and if this is done," he continues, "we shall find that many lenses are considered to be pebbles which consist of flint-glass, or even of simple crown-glass."

Why Does the Pupil Appear Black?

As simple as the answer to this question now appears to us, it remained for a long time unanswered; it was regarded as a natural fact, for which no scientific explanation could be given. Méry, in 1709, saw the retina and its vessels in the eye of a cat held under water. Afterwards, La Hire explained the phenomenon by considering that the rays of light from the retina of the cat were rendered divergent after leaving the eye by the water, and that the eye of the observer received some of these divergent rays, uniting them on his own retina, and, as a consequence, saw the interior of the cat's eye. Beher, in 1839, added to the previously existing knowledge of this subject by experimenting on an eye in which the iris was absent. Brücke came very near solving the mystery, but failed to arrive quite at the true explanation. It is a law of optics that a ray of light, after passing through a refracting medium, on being thrown back, exactly retraces its first course; hence, when rays enter the eye they are

so refracted as to unite in a point at or near the retina, a part of the rays are absorbed by the tapetum or dark pigment of the choroid, another part is reflected or thrown back, and, according to the established law, retrace their first course. If the observed eye be accurately accommodated for the illuminating flame, the reflected rays will pass directly back to the source of light; the image and the flame will be images of each other. For an observer to see into the illuminated eye, he must place his own eye in the course of the returning rays; but in so doing, he shuts out the incident light, consequently, he sees only his own dark pupil reflected.* If the light be placed by the side of the eye of the observer, and the latter be protected by a screen from the direct rays, then if the observed eye be accommodated for some other point than the light of the candle, all the reflected rays will not pass directly back to the candle, and the observer will receive some of them in his own eye, and, as a consequence, a faint reddish reflex from the observed pupil will be seen. If the pupil of the observer could be an independent source of illumination, then the observed and observer could reciprocally see the fundus of each other's eyes. As soon as Helmholtz discovered the true cause of the pupil under ordinary circumstances appearing dark, he at once put the knowledge to practical use by inventing the ophthalmoscope, an instrument which ranks equal in importance with any of the inventions of the nineteenth century.

* In my lectures, I am in the habit of illustrating the effect of interposing the eye of the observer in the course of the incident light, by placing a small picture in the bottom of a long, narrow metal tube, as, for example, a gun-barrel. If the tube be placed in the direct sunlight, so that the rays pass down the barrel, the picture will be illuminated, and the reflected rays return nearly in the course of their entrance. Now, if the observer attempt to see the picture at the bottom of the barrel, his eye shuts out the direct rays, and he sees the interior of the tube dark. If the ends of the barrel be reversed, and the sunlight be reflected into it by a plane mirror having a small opening made by removing a portion of the metallic covering, the eye placed behind the opening will see the picture. In the eye, the rays are refracted both before and after reflection.

By means of it we are enabled to observe the interior structures of the eye as they appear in health and in disease, to determine the errors of refraction, to watch pathological changes as they progress, to ascertain the nature and extent of these changes, and thus to apply rational treatment to each individual case, or to decide at once whether or not the lesions are beyond the reach of remedial measures.

The Ophthalmoscope.

After Helmholtz demonstrated the true cause why the pupil appears black, it became evident that, in order to see the bottom of the eye, it is only necessary to place the pupil of the observer in the course of the returning rays, and he at first accomplished this by placing by the side of the eye he wished to examine a lighted lamp. He then held in front of his own eye a strip of plate-glass, in such a position that the rays from the lamp were reflected into the pupil of the observed eye; the returning rays were then in part, after falling on the surface of the glass, reflected back to their source; another part was transmitted through the glass and reached his own eye, and, as a consequence, he saw the red reflex from the fundus of the observed eye, thus demonstrating the correctness of his conclusions. This form of ophthalmoscope does not illuminate the eye sufficiently, and the observer receives but a comparatively faint image upon his retina—too feeble for him to sharply separate the sensations produced by reflected light from the different parts of the fundus of the observed eye. In order to increase the illumination, another form of ophthalmoscope has been constructed. In place of using plate-glass for a reflector, a small round mirror of polished steel or silvered glass is substituted, and in its centre is a small perforation, to allow the rays to pass through to the eye of the observer. Instead of the divergent rays from the lamp, these are rendered convergent by means of a convex lens, so placed as to throw a converging cone on the plain mirror, which, after reflection, con-

tinues convergent, and the observed eye, placed at a proper distance, receives through its pupil the apex of the cone; the rays cross in the vitreous humor and fall on the retina in circles of diffusion, illuminating the parts on which the light falls. A portion of this diffuse light, provided the eye be emmetropic and adjusted for the far point, takes the same backward course as rays that are parallel when entering the eye, consequently they emerge parallel; those passing through the small opening in the mirror are received by the eye of the observer, and if his accommodation be relaxed, he sees a virtual, erect, magnified image of the retina of the observed eye. If the observed eye be myopic or accommodated for a nearer point, then the emerging rays will be convergent, and must be rendered parallel by a concave lens before the observer can see the retina of the observed eye. A concave mirror with a focal length of 6″ to 10″ has been substituted for the plain one, to obviate the necessity of using a convex lens to produce a convergent cone of light.

Actual Inverted Image.

To obtain an actual inverted aerial image of the fundus of the eye, a convex lens of short focal length must be placed near the observed eye. The convergent rays, after passing through the lens, become still more convergent; they cross before reaching the retina, and illuminate that part of the fundus on which they fall; the returning rays emerge from the eye either parallel or slightly divergent, fall on the lens and are united in its focus, thus forming an actual inverted aerial image of the illuminated portion of the retina. The observer accommodates his eye for this image, and obtains a distinct, sharply-defined view of the retina and its blood-vessels, the details all appearing in a plane. In order to obtain a binocular view of the ocular fundus, Giraud Teulon constructed a binocular ophthalmoscope which divides the fasciculus of rays into two parts, by means of two rhomboidal prisms of glass, with their edges

placed in apposition, behind the hole in the mirror. (Fig. 7, page 33.) The surfaces of the prisms are so ground that each produces double total reflection at angles of 45°. The combined lengths of the rhombs are such that the emerging rays from each fall in the axis of vision of the corresponding eye of the observer; with but slight efforts of convergence, he is enabled to fuse the two retinal images, and thus get a stereoscopic view of the fundus of the observed eye, from the actual inverted image; the blood-vessels, elevations, and depressions of the retina are seen in bold relief instead of in a plane, as with the monocular ophthalmoscope.

Entoptic Phenomena.

The refractive media of the eye are said to be perfectly transparent. They are so under ordinary circumstances; but under certain other circumstances, minute opaque bodies resting on the surface of the cornea, in the crystalline lens, and others fixed or floating in the vitreous humor, cast visible shadows on the retina. These bodies are very small in comparison with the size of the cone or pencil of light passing through the unobstructed pupil. In the first part of this work, it has been shown that a hair placed in the light of the sun casts no shadow on a screen held a few inches distant; but if the source of illumination be a point, a shadow is formed at any distance at which the screen may be held. This phenomenon is explained by the laws of diffraction. The same explanation is applicable to the phenomena of entoptic perceptions of the shadows of opaque bodies in the refractive media of the eye. Ordinarily, the amount of light admitted through the large surface of the unobstructed pupil acts on the opaque bodies in the same manner as the sun on the hair. The rays of light bend around the minute bodies, and their shadows are washed out or obliterated before reaching the retina; but if the light admitted into the eye comes from a luminous point, these opaque bodies cast visible shadows on the retina. A luminous point, for this purpose,

may be obtained by concentrating, by means of a strong convex lens, the light of a lamp on a small perforation made by a fine needle in a blackened card. If the luminous point be held nearer the eye than its anterior focus, the rays will be divergent in the vitreous humor and the shadows will be larger than the opaque bodies; if held at the anterior focus, the rays in the vitreous will be parallel and the shadows will be of the same size as the opaque bodies. If the luminous point be farther from the eye than its anterior focus, the rays will be convergent and shadows will be smaller than the objects casting them. Instead of a luminous point produced in the manner above specified, we may use feebler diffuse light from the sky, or from a ground- or milk glass globe over a gaslight, or a sheet of white paper placed before a brightly burning lamp. The part of the retina illuminated corresponds with the size of the circles of diffusion from the luminous point. It is only luminous points that project sharply-defined shadows, and as the opening through which the light is admitted has an appreciable surface, the contours of the shadows are not perfectly sharp, but are surrounded by a graduated penumbra, which gradually disappears in the illuminated surface. If the luminous point be very minute, the borders of the shadows will be surrounded by alternate lines of light and dark fringes of diffraction; with a larger luminous surface these fringes disappear in the *penumbra*. The nearer the opaque bodies are to the retina, the more sharply defined will be the borders of the shadows.

On looking at the hole in the card, which is illuminated by the light concentrated in a point by the convex lens, or by diffused light of the sky, or a lamp covered by a ground-glass shade, we see on the surface of the cornea stripes dependent on layers of moisture and mucus pushed before the edges of the eyelids, also fat globules secreted and thrown off by the palpebral glands, bubbles of air, etc. In the spectrum of the crystalline lens, which, to be distinctly visible, requires the luminous point to be very small, the

illumination is then less, and the whole surface appears as if covered by crape. We see pearl spots having nearly round disks with circumscribed dark margins; these are more numerous near the periphery, and are better seen when the pupil is widely dilated. Black spots are less frequently observed; they are either round or of an irregularly angular or oblong form. Also may be seen white lines with dark boundaries, radiating from a centre, and which correspond to the lines of separation between the different sectors of the lens. The number of these bodies increases with advancing years, and is one of the causes of the diminution of vision which accompanies old age. In forming the spectrum of the vitreous humor, we may use a card having a larger perforation, because the opaque bodies are nearer to the retina; on looking through the hole directed towards the illumination, *muscæ volitantes* are seen in great numbers floating in the vitreous; they are apparently falling in the visual field, but in reality, having a less specific gravity than the vitreous, are rising to the top of the eye. Some of these bodies are seen as isolated little circles, some with dark, others with pale contours with a bright centre; also coherent groups of little bodies connected by threads resembling strings of pearls. These floating bodies mingle with the vitreous whenever the eye is quickly moved, and gradually fall in the field of vision when the eye is at rest. Muscæ volitantes are found in all eyes, but after vascular disturbance their number and size greatly increase, so as to produce more or less disturbance of vision, and often create forebodings of future loss of vision. Their presence need not create unnecessary alarm, except in high grades of myopia. Donders says, in reference to this subject, "that few symptoms prove so alarming to persons of a nervous habit or constitution as muscæ volitantes, and they immediately suppose that they are about to lose their sight by cataract or amaurosis. Often, alas! this anxiety is even still kept up by ignorant practitioners."

Entoptic Perception of the Retinal Vessels.

Helmholtz gives three different methods which may be employed to obtain a perception of the retinal vessels.

1st. By concentrating in a small point on the sclerotica, as far as possible from the cornea, by means of a strong convex lens, a very intense light — that of the sun is the best. If the eye be turned towards a dark back-ground, the visual field seems illuminated by a yellowish-red light, in which appears a plexus of dark vessels, resembling the branches of a tree. The plexus corresponds to the blood-vessels of the retina. They are much more distinctly seen if the bright point — which should be very small — is moved to and fro on the sclerotica. The explanation of this phenomenon is this. The sclerotic coat is translucent, and permits the diffuse light to pass through it; it is transmitted in the same manner by the choroidal coat, and thus the interior of the eye is illuminated. As shown in Fig. 49, *v* represents the section of a retinal vessel; *k*, the nodal point of the eye. When the focus of incident light falls on the sclerotica, at *a*, it enters the eye, and casts a shadow of *v* on the retina, at *a′*; the eye then projects the shadow as a dark line in the visual field, in the direction *a′* A.

Figure 49.

If the light falls on *b*, the shadow is cast on B′, and a dark line is seen in the visual field at B.

2d. The second method employed for the observation of the retinal vessels is as follows: When the eye is turned towards a dark back-ground, a brightly burning lamp is held by its side, or beneath it, and moved up and down, or laterally to and fro; soon the background is covered by a whitish reflection, on which are de-

picted the dark shadows of the retinal vessels. If the light be placed laterally, we principally see the vertical vessels; if vertically, the horizontal vessels are more distinctly visible. The shadows are formed in a manner similar to those above described, except that the light, instead of passing directly through the scleral and choroidal coats, passes obliquely through the pupil and illuminates the opposite side of the interior of the eye, where it is reflected so as to form the shadows, which are projected outwards, as shown in the preceding figure.

3d. The third method of observing the retinal vessels consists in looking through a small hole in a blackened card at a brightly illuminated field — as the sky — and giving the card a rapid motion to and fro. The retinal vessels appear very finely depicted in shadows on the bright back-ground. If the movements are horizontal, only the vertical vessels are seen; if vertical, the horizontal ones come in view. The same phenomenon can be observed by looking at an object in a compound microscope. The eye should be placed above the instrument, so as to see the uniform illumination of the diaphragm, when, by a little motion of the head, the retinal vessels are very finely and very sharply projected as shadowy lines in the field of the instrument.

VISUAL SENSATIONS.

As formerly stated, the excitation of the optic nerve causes a sensation of light. This result can be produced by various means, as by a blow on the head or on the eye. This fact is so well known that many persons, in describing the severity of a blow which they have received, remark that "it made me see stars." In removing the eye for cancerous or other affections, the act of dividing the optic nerve, although causing scarcely any pain, is often accompanied by a vivid sensation of light resembling that produced by a flash of lightning. In certain diseased conditions of the nervous structure of the eye, when the sensibility of the retina is entirely destroyed, and all quantitative perception of light has long since disappeared, luminous chains, rings, sparks or flashes of light, are often seen, and sometimes are of such frequent occurrence as to cause considerable annoyance. The irritation of the stump of the optic nerve left after the enucleation of the eye causes luminous sensations. Increased pressure of blood and weak electrical currents passed through the optic nerve, even far within the brain, cause a sensation of light. More prolonged luminous sensations may be produced by pressing the side of the globe of the eye with some small, hard substance, as, for instance, the finger-nail. The retina immediately beneath the pressure is excited, and luminous rings appear in the field of vision on the opposite side; these are called *phosphenes.* These phenomena have been studied with much care by Purkinje and Czermak, and a great variety have been produced and recorded. The effect is most decided when the nail is pressed on the equator of the globe where the sclerotic coat is the thinnest. None of these means of excitation of the optic nerve are available for the perception of external objects. The only excitant of the sensitive fibres of the nerve

that makes us conscious of the existence of objects situated in space, are waves of elastic ether entering the eye and falling on the retina, thus producing mechanical irritation, causing a continuous sensation of light for an indefinite period of time, or as long as the ether waves are permitted to enter the eye. Waves of ether having the longest periods of duration when they fall on the skin cause a sensation of heat, but falling on the retina produce no luminous impression; on the contrary, waves having shorter periods of duration, falling on the skin scarcely produce any sensible heat, but entering the eye and impinging on the retina, cause a sensation of light. It is to the luminous sensation caused by waves of elastic ether falling upon the retina that has been given the name of *light*. It is evident that light does not exist in nature; it is simply a sensation produced by mechanical irritation of nerves of special sensation. Waves of elastic ether falling on the body of the nerve produce no sensible effect. A cone of luminous rays thrown into the eye with the ophthalmoscope, its apex falling on the optic disk, penetrates the nerve, rendering blood-vessels situated at a considerable depth visible, and returns, yet no sensation is felt beyond a feeble illumination, caused by diffuse light or reflected rays from the nerve surface striking the retina. The moment that the apex of the cone passes from the disk and falls on the retina, a most intense luminous sensation is felt. The optic disk, the space occupied by the entrance of the optic nerve and its blood-vessels into the eye, is situated in the horizontal meridian, at the nasal side of the posterior scleral pole, and its vertical dimensions form an angle at the optical centre of the eye of about 6°; horizontally of 8°. Its inner border is about 12°, horizontally, from the external side of the fovea centralis. On the disk the image makes no impression, hence it is known as the *Punctum Coecum*, or Blind Spot of Mariotte, after the name of its discoverer. The announcement of this discovery created much excitement among the learned men of Europe, and Mariotte was induced to repeat many amus-

ing experiments, showing the insensibility of this point, before the king of England, in 1668. Among these was one which consisted in placing twelve men in a line, in such a position that one of them appeared without a head. The position of the blind spot may easily be found by the following experiment. Place on the right thumb-nail a small piece of white paper, close the left eye and hold both thumbs side by side directly in front of the eye, in the horizontal plane, ten or twelve inches distant; keep the eye steadily fixed on the nail of the left thumb, and move the one covered with the paper to the right; at a distance of four or five inches the image of the paper falls on the optic disk and it becomes invisible. Move the thumb a little to the right, left, upwards, or downwards, and the paper again comes in view. The same can be shown by looking at Fig. 50. If the left eye be

Figure 50.

closed and the page held vertically before the right, the eye being steadily fixed on the cross at the left-hand side of the figure, then if the book be slowly moved backwards and forwards, at some point eight or ten inches distant from the eye, the white spot has its image formed directly on the optic nerve, and disappears from view. Helmholtz, in alluding to the size of the blind spot, states that eleven full moons placed side by side might have their images formed on the optic disk and be invisible, and that the figure of a man, at the distance of seven or eight feet, may disappear from view.

The retina is formed by the expansion of the optic nerve, and lies between the choroid coat and vitreous humor. It is transparent, and contains, besides formations peculiar to itself, microscopic elements found in other nervous tissues, and is composed of several different layers, some of which are known as nerve layers proper, others as mosaic layers; the latter are the external granular, and the rods and cones which terminate in the posterior layer of the retina, and are

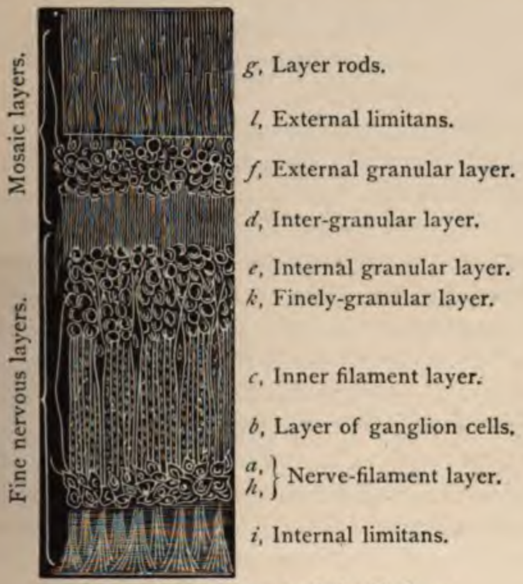


Figure 51. Anatomy of the Retina.

regarded as having an intimate connection with the specific sense of vision. These are shown in Fig. 51, after H. Müller.

The rods and cones are unequally distributed in the retina; towards its periphery they are scattered, but on approaching the yellow spot they become more numerous. The yellow spot, which is found only in man and monkeys, takes its name from its color, is situated a little to the temporal side of the posterior scleral pole, and has in its centre a depression where the nerve fibres proper are

wanting, called fovea centralis. This part of the retina is very thin and transparent, easily broken, and might be mistaken for an opening; here are found only cones, which are exceedingly small and closely pressed together, like mosaic work, so that many are concentrated in a small space. The walls of the rods and cones are reflecting surfaces, and are arranged in such a manner that light entering the element is thrown back, so that no rays pass from one to another. Each rod and cone is connected with the brain by a delicate nerve-thread, — those of the rods, being the largest, running through the optic nerve in bundles of several threads each, enclosed in separate envelopes or sheaths. Helmholtz estimates their number at two hundred and fifty thousand. The same insensibility to objective light that exists in the optic nerve extends along the course of the nerve fibres of the retina; it is only the rods and cones that are capable of being excited by oscillations of elastic ether. It is certain that the posterior layers of the retina are sensitive to light, because, as shown on page 118, the shadows of vessels within the retina can be perceived, and they must necessarily be formed on the posterior part of this structure. The diameter of the cones in the fovea centralis is variously estimated at from 0·0015 *mm.* to 0·0036 *mm.* The excitation of an element is only capable of producing a single sensation, hence the brain cannot separate impressions made on a single element caused by unequal degrees of illumination. We can perceive a luminous point, the image of which is much smaller than a sensitive element, provided a sufficient quantity of light enters the eye; thus, a very small star can be perceived, but, according to Hooke, two stars of which the apparent distance is less than 30 seconds always appear as a single star, because the images of both fall on a single element, and the brain cannot separate the two impressions, hence, receives but a single sensation, and as a consequence, the two stars are mingled into one; or, if the images of two stars formed on contiguous elements, the space between them may fall on

the line of contact between the two cones. For two stars to be perceived, their images must be formed on two elements separated by a third intervening one, on which the space between the images may fall. Few eyes can distinguish between two luminous points separated by a less distance than 60 seconds. A visual angle of 60 seconds corresponds on the retina to a space of 0·00438 *mm.* In order that two luminous points, separated by a sufficient distance to have their images on contiguous elements, may produce sensations capable of being separately distinguished, there must be a certain difference in the color or degree of illumination of the points.

The acuteness of vision is not the same in all parts of the retina; it is greatest at the macula lutea, and rapidly diminishes towards the periphery, but not in equal degrees. Upwards and downwards the diminution is more rapid than inwards, while the greatest acuteness of peripheral vision is on the temporal side of the retina The acuteness of vision is usually measured by means of the test-letters of Snellen. This method will be fully explained when we come to treat of visual perception.

Measurement of the Field of Vision. — Various means have been devised to measure the extent of the visual field, and some ingenious instruments have been invented for accomplishing this end; but in ordinary practice, a black-board three or four feet square, having a small white dot in the centre, may be employed for the purpose. The person whose eye is to be examined should be seated about a foot from the board, with his eye directly in front of the central dot, the other being covered. It is better to have the head fixed so as to be immovable. The uncovered eye should be unchangeably placed on the central white spot, when the examiner should take a piece of white chalk between his fingers and place it near the top of the board, and gradually bring it toward the centre; as soon as the chalk comes into view of the examined eye, a mark should be made on the board, and

another position taken at a little distance from the first, the chalk made to approach the centre in the same manner and a mark made at the point where the chalk comes into view. This should be repeated at short distances until the place of the appearance of the chalk has been noted in many different directions; then a line connecting various points may be drawn; this line indicates the extent of the visual field; in which space, all objects, except those whose images fall on the blind spot, can be seen at a single glance; those only, however, whose images are formed on the yellow spot are sharply defined.

Simple Colors.

The wave theory of light has been explained in the part of this work devoted to physical optics. The reader, if not thoroughly familiar with that theory, should refer to it in connection with the subject of this chapter. It may be proper, however, here to recapitulate some of the views there given. All known sources of light throw the elastic ether, which occupies all space and permeates material bodies, into undulations or waves. These are of unequal length, but all travel equal distances through a homogeneous medium in the same period of time; consequently, there must be an increased number of the shorter waves in order to keep pace with the longer ones, therefore, the number of light waves of any specified length that enters the eye in a given period of time depends on their length or period of duration. Waves of different lengths have different degrees of refrangibility, and on passing through a prism are separated; thus, sun or white light passed through a strong prism has the waves of which it is composed bent so as to take different directions, forming the solar spectrum. The least refrangible rays falling on the retina produce the red color; then, as the oscillations diminish in length, we have in regular succession the orange, yellow, green, blue, indigo, and violet — the waves causing the latter sensation having the shortest period of duration.

A system of waves of ether having a uniform length or period of duration produces a simple color or light. The ultra-violet waves have periods of durations too short to produce light under ordinary circumstances, but they cause certain chemical effects, hence, are known as chemical rays; if passed through certain substances, as, for instance, a solution of the sulphate of quinine, the lengths of the waves are increased, giving rise to a purplish light known as fluorescence. If the simple colors of the solar spectrum are reblended by means of a convex cylindrical lens, the original white light is reproduced.

Compound Colors.— It has been shown that homogeneous light, according to the different degree of refrangibility and duration of oscillation, gives rise to the sensations of different simple colors. If the same portion of the retina be struck simultaneously by two or more waves having different periods of oscillation, the sensation of another color is experienced, differing from either of the primary ones. When the sensations of two or more simple colors of the spectrum are blended, forming a new color, the eye cannot in general distinguish the primary colors entering into its composition. The ear, on the contrary, when simultaneously struck by aerial waves of different periods of oscillation, unites the sensations in one accord, and is always able instantly to distinguish separately each compound sound. Some have thought themselves able to separately distinguish the primary colors entering into the composition of the simpler forms of compound light, but this cannot be done by an act of sensation, but by an act of judgment based on the results of information gained from experiments. No one can realize the fact, from a simple act of sensation, that white light is composed of the seven primary colors.

Complementary Colors are those, any two of which, when mixed together, produce white. Of the simple colors of the spectrum, we have the following pairs that are complementary:

Red and greenish blue.
Orange and cyanogen blue.
Yellow and indigo blue.
Greenish yellow and violet.

Complementary broken colors are almost innumerable. Natural bodies have the power of absorbing or quenching a part or all of the light which falls on them. If all the light is absorbed or quenched, none is reflected, hence the body appears black. When all the rays are partially, but equally absorbed, the reflected color is gray. If all the colors but one are quenched, that one is thrown off, enters the eye, and gives its color to the object. If all the colors of the spectrum are absorbed by a body except the green, its color will be green. If all but the red, its color will be red.

The mingling in different proportions of the unabsorbed waves of ether gives rise to all the various shades of color. If pigments or powders could be obtained exactly corresponding to the simple colors of the spectrum, their mixture would make pure white, but these, as yet, have not been found; the nearest approach to white being gray. Transparent substances transmit the colors which they do not absorb. Glass of pure red quenches all the other colors and transmits the red.

Yellow glass allows the yellow colors to pass, and also some of the green and orange. Blue glass transmits not only the blue rays, but also a portion of the adjoining green and indigo.

White light, after passing through blue and yellow glass, appears green — the only color transmissible by both.

It is evident that this would not be the case if these pigments were pure colors, for then either glass would quench all the light except that of its own color, and that one alone would be transmitted to the second glass; but the purest pigments of blue and yellow contain some green, hence they do

not quench all the green rays passing through them, and the result is as above stated.

Blue and yellow powders mixed give green, but blue and yellow rays of light produce white — because they are complementary colors. A body placed in light which it cannot transmit or reflect, appears black; thus, red sealing-wax in the green of the spectrum seems black; so red flannel placed in the spectrum shows its color where the red rays fall upon it, but black in all the other colors. The persistence of retinal impressions enables us to blend the sensations of color. If a wheel, on which the colors of the spectrum are painted in sectors, be rotated, the simple colors will disappear; the greater the rapidity of motion the nearer the disk approaches white. If the revolutions be sufficiently rapid, the resulting sensation will be that of pure white.

Red and green	rotated	on the	disk	produce	white.
Yellow and violet	"	"	"	"	"
Blue and orange	"	"	"	"	"
Blue and yellow	"	"	"	"	green.
Red and yellow	"	"	"	"	orange.
Blue and red	"	"	"	"	purple.

Fundamental Colors.

Any three colors, the mixture of which produces white, may be regarded as fundamental colors, because each of the other colors may be formed by a mixture of these in various proportions. Red, yellow, and blue, are generally regarded as the fundamental colors; but Helmholtz, for reasons which to him are satisfactory, but to give which would occupy too much space, prefers to take the red, green, and violet. Thomas Young entertained the opinion that there exist in the eye three kinds of nerve fibres, the excitation of which gives respectively red, green, and violet. "The simple red excites strongly the sensitive fibres of the red, and feebly those of the other two species; sensation: red. The simple yellow excites moderately the sensitive fibres of the red and

9

of the green, feebly those of the violet; sensation: yellow. The simple green excites strongly the fibres of the green, much more feebly the other two species; sensation: green. The simple blue excites moderately the fibres of the green and of the violet, feebly those of the red; sensation: blue. The simple violet excites strongly the fibres which belong to it, feebly those of the others; sensation: violet. The excitation very nearly equally of all the fibres, gives the sensations of *white*, or of the white color." (*Helmholtz Physiological Optics.*) This hypothesis Helmholtz considers probably true, as it explains some phenomena not otherwise accounted for, and is not, in the present state of our knowledge, contradicted by any known facts.

Color-Blindness.

Occasionally persons are met with whose eyes are insensible to certain colors (*Dyschromatopsia*). Of these the most common is insensibility to red rays (*Anerythropsia*), sometimes called *Daltonism*, after Dalton, the distinguished philosopher, who had this defect in his own eyes, and who first described it. But some of the English savants disclaim this name, and object to this method of perpetuating the memory of their distinguished compatriot by recalling his physical defect. Those in whom this defect is completely developed see in the spectrum but two colors, which they designate under the names of blue and yellow. They apply the latter name to all the red, orange, and yellow; and the green they call bluish-green, and all the other colors blue. They do not see the red at all, or only when it is very intense. Among the colors of bodies they confound the red with brown and green. Red is absent in their system of colors. "All tints are for them varieties of blue and green, or, as they call it, yellow. Accordingly, scarlet, flesh-color, white, and bluish-green appear to them to be identical, or at the utmost to differ only in brightness. The same applies to crimson, violet, blue, and to red, orange, yellow, and green." (*Helmholtz.*)

J. Herschel advanced the opinion that all the colors which those affected with Daltonism are able to distinguish, may be considered as composed of two fundamental colors instead of three. Maxwell has more recently, after numerous experiments made with rotary disks, confirmed the views of Herschel.

Persons whose eyes are insensible to green (green-blindness) are more rarely seen. They find it difficult to discriminate between green, yellow, blue, and red.

A knowledge of the existence of these defects of vision is a matter of great importance in the present age of railroads and steamboats, when cars and boats are guided at night by different colored signal-lights, and the lives of thousands of passengers depend upon a proper appreciation of the different colors by those having charge of the running of boats or trains at night. Persons having this anomaly of vision are generally unaware of it themselves.

No engineer, pilot, or master of a signal station should be permitted to serve in that capacity until he has been thoroughly examined and found to be free from color-blindness; or, at least, he should have a proper appreciation of red and green, colors most frequently used for signal-lights. Doubtless many accidents have happened, and lives and property have been sacrificed, by the neglect of this rule, when the engineer or pilot was careful, attentive, and otherwise competent, but was unable to distinguish the red from the green light, or mistook the green for the red.

Dr. Favre, physician to the Paris and Lyons railroad, found, between the years 1864 and '68, in 1196 men examined by him, 13 cases of insensibility to red rays and 1 to green. In the years 1872–73 he examined 728 men, and found 42 cases of Daltonism, or more or less insensibility to red rays.

Persistence of Retinal Impressions.

When a motor nerve is excited by an electric current of short duration, it is about one-sixtieth of a second before the muscle contracts, and it continues to act for about one-sixth of a second. In the eye, when an impression is made on the special nervous apparatus, an interval of time elapses before the impression is transformed into a sensation, which has a certain period of duration. If that impression be made by an electric spark, which may be regarded as instantaneous, and if owing to the persistence of the sensation, other sparks rapidly succeed each other before the sensation produced by each preceding one has passed away, the perception cannot separate the sensations caused by each spark. From this it is seen that luminous impressions made with sufficient rapidity produce the same effect on the retina as a continuous illumination. If we gaze fixedly for a short time at a gas-light in a dark room where there is no other light, and then suddenly extinguish it, we shall continue for some moments to see the flame, and if the eye be moved the flame will follow the motions of the eye. The period of duration of impressions varies with different persons; this can be measured by causing an illuminated point — as a burning coal or a small piece of iron heated to whiteness — to revolve on a rotary disk attached to machinery so arranged that the time of revolution can be recorded. The length of time required for one revolution to produce the impression of a closed circle of light measures the duration of the first impression. If the point revolves with less rapidity there will be a break in the circle, because the impression made at the starting point has passed away before the revolution is completed. A very great variety of interesting and instructive experiments illustrating this subject can be made by means of rotary disks.

After-Images.

When the eyes are for a length of time exposed to a bright light, the retina becomes, as it were, paralyzed, and it is for a while more or less insensible to a weaker light, as is illustrated by being out in the open air for a length of time when the sun is shining on fields of snow; on entering a moderately illuminated room it seems dark, and objects cannot be recognized. Soon the paralysis begins to diminish, and in a little time everything visible in the room can be distinctly seen, and fine print easily read. This is familiarly called snow-blindness. Persons confined for a long time in dark cells have the retinal sensations so acute that they can read ordinary print, when a person who has just entered can scarcely recognize features. Nervous exhaustion of local portions of the retina can easily be induced. If we place a sheet of white paper against a wall on which the sun is brightly shining, and gaze at it fixedly for a minute or two with one eye, holding an object, *e. g.*, a cedar pencil, between it and the paper, on removing the former, without changing the direction of the eye, that part of the paper which was covered from view by the pencil forms a line of dazzling whiteness. Again, if we place beside the sheet of white paper a black one, having on it a narrow strip of white, and gaze for a time on the latter, then on turning the eye to the white sheet, it will appear of dazzling whiteness, with a dark line corresponding to the white strip on a dark back-ground. These persisting impressions begin to diminish after the first second, and generally at the end of one or two minutes completely disappear. The dark parts of the image appear bright and the light parts dark in the after-image, so that the latter is just the negative of the former, like the first negative of a photograph. *Accidental* or *after-images* are distinguished as *positive* and *negative*. Positive persistent or after-images are those in which the light and dark parts of the objects appear equally light and dark. *Negative* after-

images are those in which the light parts appear dark and the dark parts light. Often, meditative persons, gazing unconsciously for a long time on some object, on suddenly turning their eyes upwards, see an after-image greatly magnified apparently in the clear gray or blue sky. If we draw on a piece of white paper a black impression, three or four inches in length, of a dagger or sword, and fix the eyes on it when brightly illuminated by direct sunlight, and gaze at it steadily for two or three minutes, and then turn the eyes suddenly upwards, we shall see in the clear sky the image of a flaming dagger or sword. If the object looked at be white, the after-image in the sky will be dark, and *vice versâ*. Doubtless these phenomena of after-images account for the sights seen in visions, in former times, by persons having a morbidly sensitive retina, and which were thought to be connected with manifestations of a supernatural power. Parts of the retina impressed by certain colors can be saturated, or paralyzed by nervous exhaustion, by gazing steadily for some time on any one of these colors brightly illuminated. For illustration, if we look for two or three minutes at a bright red surface, all the retina, or that part of it on which the image is formed, becomes red blind; now, if the eye be turned towards a sheet of white paper, the latter, or that part of it covered by the after-image, appears of a bluish-green, the complementary color of red. Again, if we expose the eye to bluish-green, the after-image appears of a bright red. The effect on the spectrum caused by the exhaustion of the retina for any particular color, is the same as if that color were removed and its complementary color substituted. When the excitability of the nervous structure is morbidly increased, these after-images often last for days, and become very annoying. "In suddenly changing the direction of the eyes, it readily occurs that, while another object has come under observation, the impression of the former one is still present, and, consequently, the after-images are mingled with the impression of the objects still in sight; the perceptions become confused,

and, since the after-images change their positions with the movements of the eyes, an apparent motion is imparted to the objects which are really at rest." (*Stellwag.*)

Intensity of Luminous Sensations.

In physical optics, the intensity of objective light, both simple and compound, is equal to the active force of the movements of ether. The intensity of luminous sensations is not entirely proportional to the active force of the undulations, but depends also on their duration and on the nature of the eye.

The intensity of objective light is inversely proportional to the square of the distance of the luminous source; a screen placed one hundred feet from a lamp is illuminated ten thousand times less than at the distance of one foot, yet the eye placed at the former distance experiences a luminous sensation nearly as intense as it would receive at one foot. In this illustration the contrast is very great, but even the smallest perceptible degradation of luminous sensations does not correspond to equal differences of objective brightness. In general, the smallest perceptible differences of luminous sensations are fractions of a nearly constant quantity. In the study of this subject, Fechner was induced to propose a psychophysical law, known as the Law of Fechner, applicable not only to these, but to other kinds of sensations. Under this law he has proposed to establish a relation between the intensity of light and the energy of the sensations which it produces.

The color of simple light is determined by the length of the wave or by the number of vibrations during a unit of time, as the pitch of sound is determined by the number of sonorous vibrations. The ear recognizes much more readily the pitch of two sounds, if one succeeds the other, while the eye, on the contrary, perceives at the first glance very slight differences of color of the fields placed side by side; but if the impressions are separated by the shortest interval of time, the judgment is often at fault. The ear judges purely of the equality of the

intensity of the simultaneous sounds of the same pitch; it does better if one succeeds the other. The eye better compares coëxisting intensities. We have the memories of successive sensations of the ear, while those of the eye are simultaneous. In the simultaneous comparison of luminous sensations produced by looking at two objects differently illuminated, "let 1 and $1 + a$ represent the intensities of the two illuminations; at the moment when they fall on the retina, a has still a certain value when the eye is unable to appreciate any difference between these intensities. Experiments have shown that within certain limits this quantity a, variable with the observer, changes slightly with the absolute value of the illumination taken as unity; the quantity a changes with circumstances; it varies from $\frac{1}{50}$ to $\frac{1}{150}$; this last figure is only obtained in exceptional conditions; Bouguer could distinguish the difference of $\frac{1}{84}$ between the intensities of the two lights." (*Becquerel.*)

The law of Fechner is as follows: in calling S and s the sensations produced by two luminous intensities, H and h, we have $S - s = \text{logarithm } \frac{H}{h}$.

Admitting that the perceptions are proportional to the sensations, and that the imperceptible differences of the sensations have always the same small degree of variation; in translating, into algebraic language, this fact, the smallest perceptible differences of sensation are constant fractions of intensity, and we have $d\,S = A \frac{d\,H}{H}$, A being a constant quantity; this integral relation leads to the expression above given. The experimental fact is that $\frac{d\,H}{H}$, mentioned above as a, is constant for the same individual under the same circumstances, and the hypothesis is that d S, the difference of sensation that ceases to be perceived, is constant.

The law of Fechner is approximately exact only when applied to the mean limits of intensity. The variations are much greater when near the extreme limits of greatest and least intensity, particularly the former, the reason of which

he attributes to fatigue of the eyes when exercised in determining the sensations produced by the extreme limits of objective brightness. Helmholtz, however, states that when the illumination is very feeble, we may consider the intensity of the sensation as proportional to that of the light, while under an intense illumination the sensibility for luminous objects is relatively more feeble. As we are more accustomed to examine objects with a strong illumination, bright objects, when the light is feeble, appear to us relatively too bright and dark shades relatively too dark. Painters, in order to produce more decided effects, utilize this fact. To give the sensation of feeble illumination to objects, they represent scenes in a misty atmosphere or by moonlight, thus causing the light parts of objects to appear more striking than when represented by clear daylight.

Comparison between the Intensities of Lights of Different Colors.

"The intensity of the luminous sensations depends not only on the active force of the undulations of ether, but also on the durations of these undulations. It follows from this that all comparisons effected by aid of the eye between the intensities of different kinds of compound light possess no objective value independent of the nature of the eye." (*Helmholtz.*)

It has previously been shown that for the same kind of light the sensation does not increase proportionally to the intensity of objective light. In the comparison of different kinds of objective light, "*the intensity of sensation is a function of luminous intensity which differs according to the kind of light.*"

It generally requires a stronger illumination to cause the sensations produced by the less refrangible rays of the spectrum than is required for rays of greater refrangibility. For illustration, if two pieces of paper, one red the other blue, be placed on a wall illuminated by daylight, the room

gradually darkened, the red color will disappear from view and appear black when the blue remains distinctly visible.

Helmholtz states, that when we linger in a gallery of paintings while twilight is casting her mantle over the earth, if the sky be clear, the red colors will be the first to fade and then disappear from view, while the blue remain visible a long time afterwards. In the darkness of night, when the colors of surrounding objects cannot be distinguished, the blue color of the skies can be distinctly seen.

Irradiation.

We understand by irradiation a series of phenomena in which a limited field, much more brightly illuminated than the back-ground on which it is projected, appears much

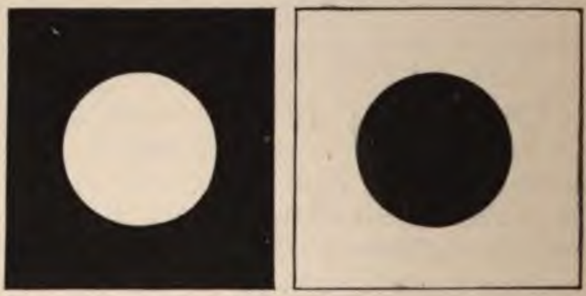


Figure 52.

larger than it really is, and reciprocally a dark limited field projected on a bright back-ground, appears much smaller than it is in reality. It is thus that narrow slits, when admitting bright light, appear wider than they actually are. The ancients were aware of this fact. We find the following in Becquerel: " M. Plateau, dans ses recherches sur l'irradiation, cite le commencement de la troisième satire de Perse: Déjà la clarté du matin se fraye un passage par les fenêtres et la lumière élargit les fentes étroites."

The appearance of a white surface on a dark back-ground is represented in Fig. 52. The black and white circles are of

exactly the same dimensions, yet the white appears much the larger of the two. The effect is more striking when the figures are removed a little beyond the far point of distinct vision, that is, at a distance of forty or more feet. Fig. 53 represents a circle half white on a dark back-ground, and the other half black on a white background. It will be seen that the white portion appears larger and the black smaller than it actually is. Beyond the far point of distinct vision diffusion circles are added to diffraction, and increase the effect. Cloth or paper printed in dark and white stripes, of equal width, presents to the eyes an appearance of greater width of the white stripes. The openings between the slats of a window-blind, on which a bright light is shining, appear wider than they are in reality, owing to the effects of irradiation, to which may be added the diffusion of the light on the surfaces of the slats. It is owing to irradiation that the moon just appearing above the horizon looks unnaturally large, for it is seen surrounded by the feebly illuminated mist that rests near the surface of the earth.

Figure 53.

The apparent diameter of Venus, as estimated by Tycho Brahe, was 12′ 18″, while Lansberg found it 12′ 21″, and Kepler 6′ 51″. Horrox found by his measurements that it was only 1′ 16″. These errors of observation arise from different degrees of irradiation, caused by variable misty conditions of the atmosphere at the times of observation.

VISUAL PERCEPTIONS.

In order that visual sensations may have a practical value, they must be utilized so as to make us conscious of the existence of exterior objects; for this purpose only objective light, entering the eye through the pupil, is available. Luminous waves of ether, coming either direct from the luminous source or reflected from the surfaces of bodies, pass through the refractive media and form inverted images on the retina. Impressions are made on the perceptive elements, causing local changes, the effect of which, when communicated to the brain, is projected outwards in an inverted direction to the object, thus making us conscious of the existence of the form and position of objects situated in space, although in reality we only see their inverted images. These representations are known and described as *visual perceptions*. We are unable to explain the action of the brain through which these results are accomplished, and the study of this subject properly belongs to Psychology.

In the ordinary exercise of monocular vision, the brain projects outward the impression made on each rod and cone in the direction of the primary or secondary impinging axes rays while in the vitreous humor, and as the secondary axes rays cross each other at the optical centre of the eye, it follows that all impressions made on one side of the retina are, in the field of vision, referred to the opposite side. This is the case even when a portion of the retina is mechanically excited; as, for illustration, by the finger-nail on the temporal side of the eye, the illumination appears in the nasal side of the field of vision. So if rays of light are bent before entering the eye, the position of the object seems changed. In the binocular field of vision, the line of projection outwards is modified; while in direct monocular vision, the outward projection of the impression made by the unrefracted axis ray accurately corresponds with the direction of the visual line—

which passes from the point of the object fixed, through the nodal points, to the fovea centralis; in direct vision with both eyes, the outward projection is in the direction of a common visual axis, that is, in a line drawn from the point of fixation to the middle of a line connecting the points of rotation of both eyes, or a line dividing the angle of convergence into two equal parts. The outward projections of the secondary axes rays of both eyes are arranged around this common axis, so that, although there are two images, but a single object is perceived. The effect is the same as if a single eye were placed intermediate between the two. As the perceptive elements of the nervous structures in the region of the yellow spot alone have the power of sharply separating the impressions made upon them, and as this spot occupies but a small portion of the retina, it follows that only a small part of a large object can be distinctly seen, with a fixed position of the eye, while other portions seen are shadowy, — that is, not sharply defined, — and this indistinctness of the object increases the more its image approaches the periphery of the retina. "So that the image which we receive by the eye is like a picture, minutely finished in the centre, but only roughly sketched in at the borders. . . . . To *look* at anything, means to place the eye in such a position that the image of the object falls on the small region of perfectly clear vision. This we call *direct* vision, applying the term *indirect* to that exercised with the lateral parts of the retina — indeed, all except the yellow spot." (*Helmholtz*). As an illustration, if we take the multiplication table and look at or fix some central figures, those nearest to them can be made out with difficulty, while those more peripheral are seen as dark spots, but they cannot be defined; and to see each figure distinctly, the eyes must move so that the images fall on the "small regions of perfectly clear vision."

In the exercise of sharp vision, the eyes are constantly, but to us almost unconsciously, in motion. Thus, if we watch a

person reading, we shall see their eyes fix the first word of the line, and then run along it until finished; then the eyes turn back to the commencement of the next line, to go through the same changes of the positions of the visual axes. No one can read a line of any considerable length by keeping the eyes fixed on the first word. If we examine a painting, we first look directly at one point of it, and then rapidly move the visual lines so that they successively fall on its different parts. The memory retains the impressions made by each glance, so that at the end of the examination we are enabled to form an accurate judgment of the effect produced by the painting as a whole. As a cone or rod cannot separate an impression made on it, each one is regarded as a unit, hence, the retina is susceptible of as many separate impressions as there are cones and rods, each one of which represents an aliquot part of the field of vision. Each of the many thousand points of an object seen produces a distinct and separate effect upon the sense; but as the cones are smaller and much more numerous at the seat of direct vision, it is here that the most minute details and shades of small objects are perceived. Each cone is differently impressed, according to the length of the light waves impinging on it; the brain combines the separate sensations, and thus forms its estimate of the appearance of objects, with all of their perspective outlines, angles, shades of color, down to the minutest details, and their relative positions in space to all surrounding objects as far as the vision can reach. The retention by the memory of the sensations produced on the brain by these little inverted images in the retina, becomes by far the most important medium through which we derive our ideas of space, and our knowledge of the external world. It is the first sense that the new-born infant cultivates to "catch knowledge of objects." It shows signs of pleasure at an illumination, but it does not know how to direct the eyes towards the source of the illumination. After a while the eyes, in wandering about, are fixed on the flame,

and continue to gaze on it, and the child shows signs of infantile delight. In a little while, when a candle is lighted, it begins to search for the flame, and soon learns to find it. When a simple object is given the infant, it takes it in its hands, turns it over and over, looks at it in every possible position, feels it with the fingers, carries it to the mouth, and learns to verify the judgment formed from visual sensation by the sense of touch, and thus soon becomes familiar with its external qualities and appearances, so that it is instantly recognized the moment it is again seen. The object is then thrown aside and some other simple article sought, with which it goes through the same processes, and thus learns by degrees to recognize the form, size, color, and positions of objects, and to move the eyes in such perfect harmony that the images belonging to each one respectively fall on the small place of distinct vision. Every new object seen gives rise to new ideas. The photographer, engraver, or painter, impresses on paper or canvas the perspective outlines of objects, with their minute shades of detail; the eyes look at the picture, and a single glance enables us to form definite ideas and a correct judgment of the form, size, relative positions and colors of the objects represented.

"Picture books," containing rude representations of familiar objects, are the first ones placed in the hands of children, and these assist the young minds in learning to combine the characters employed in expressing thoughts; as, for illustration, the figure of a man by the side of the letters M A N enables the child to comprehend the meaning of this combination of these three letters, and whenever they are afterwards seen so arranged instantly the idea of a man arises in its mind; so with other objects, as horses, cows, houses, etc. Owing to modern scientific researches and ingenious inventions, the facilities for impressing on paper the representations of objects are now so great that the illustrated papers and periodicals of the day have become an important means of imparting to us more correct ideas

of the appearances of objects, such as cities, buildings, scenes, landscapes, and of the forms and features of persons, etc., than could be obtained by volumes of description. While the yellow spot is acutely sensitive to the impressions of strong light, other portions of the retina are more easily impressed by a feeble light, as is proved by looking at a star of small magnitude that cannot be seen by direct vision; but by turning the visual lines to a point a little distant, so that the image falls on the retina at a distance from the yellow spot, it at once becomes visible. At the place of direct vision, a point having an angular magnitude of one minute can be perceived, but it is seen only as a point, and causes but a single sensation; were it composed of several shades and colors, these could not be separately distinguished; hence, it is usually supposed that the image formed from a body having an angular magnitude of one minute corresponds to the width of a single cone. To exercise the power of separating and measuring individual impressions requires a larger image, the necessary size, varying in different persons, and in the same person with different degrees of illumination. "The smallest angle at which objects of known size and known form can be distinguished, determines the degree of the acuteness of vision. To determine the smallest visual angle, we measure the utmost distance at which objects of definite size can be recognized. A visual angle and corresponding distance being taken as unit of measure, the proportion between such distance and that at which the object is actually seen, expresses the acuteness of vision. We take as a unit of comparison the recognition of letters, seen at an angle of five minutes. The utmost distance at which the types are recognized (d), divided by the distance at which they appear at an angle of five minutes (D), gives the formula for the acuteness of vision (v). The formula for vision is, $v = \frac{d}{D}$." (*Snellen.*)

Snellen has devised his test-types, numbering from 1 to 200, so that each one is seen at the specified distance under

an angle of five minutes. The letters are square, the lines composing them having a width of one minute or one-fifth of the height. No. I, placed at twelve inches from the eye, gives a tangent in height of 0.209 Paris inches. They are to be read at the distance in feet corresponding with their numbers. All of them, at the distances specified, make on the retina images of the same size; consequently, if No. I can be read at one foot, No. XX should be read at twenty feet, and No. CC at two hundred feet. If No. X is easily read at ten feet, then vision $= \frac{10}{10} = 1$. If No. X can only be sharply recognized at five feet, then $V = \frac{5}{10} = \frac{1}{2}$. If No. XX can only be made out at four feet, then $V = \frac{4}{20} = \frac{1}{5}$. Perfect recognition is required, and not uncertain perception of letters.

A copy of Snellen's Test-Types hangs on the walls of the office of every ophthalmic surgeon, and should be found in the shop of every optician and dealer in spectacles. If the room be sufficiently large, the letters should be placed at twenty feet from the patient, and when it is desirable to measure the sharpness of his vision for parallel rays, he is requested to read No. XX. If he does so easily, we know at once that he has normal vision for distant objects, and if weak convex glasses make the letters appear less distinct, we conclude that his eyes are emmetropic. He is then given No. I, which is held twelve inches from the eyes; if he reads this readily, he is requested to bring the card to the nearest point at which the letters can be sharply seen; if he can read them at the distance of eight inches or less, he has a normal range of accommodation. Many persons have a sharpness of vision above normal; in this country this is generally the case with persons under twenty or twenty-five years of age. Many easily read No. XX at thirty feet, and some even at a greater distance; while in Europe, "generally speaking, five minutes is the smallest visual angle at which print can be fluently read." (*Stellwag.*) Perhaps this difference can be accounted for by the greater clearness of

10

our atmosphere, as compared with that of many countries of Europe, particularly England, Germany, and France, which gives us a better illumination. The Test-Types of Jaeger, of Vienna, are also in general use, and are more particularly adapted for testing the vision in reading, when it is desirable that the patient should exercise the power of accommodation for a length of time; they are printed from such types as are usually found in publishing houses. No. 2 Jaeger corresponds to No. 1 Snellen. No. 5 J = 2 S; 7 J = 3 S; 11 J = 4 S; 13 J = 5 S; 14 J = 7 S; 17 J = 18 S; 19 J = 27 S; 20 J = 38 S. (*Stellwag.*)

Movements of the Eyes.

Each eyeball is moved by six muscles—four recti and two oblique. The four straight muscles arise, by tendinous origins, from around the border of the optic foramen; they are broad and flat, and in their course forwards strike the eyeball, when it is directed directly forwards, just behind its equator, and are inserted by broad thin tendons into the anterior half of the sclerotica, at distances from the cornea varying from two and a half to three and a half lines.

The superior oblique muscle has a tendinous origin, from near the edge of the optic foramen. Its flat belly runs forwards to the trochlea or pulley, situated at the upper and inner edge of the orbit, before reaching which, it passes into a long thin tendon; this runs through the pulley, and immediately turns backwards and outwards, becomes gradually broader, spreading out like a fan, and is inserted into the upper, outer, and posterior quadrant of the eyeball. The inferior oblique arises from the lower and inner portion of the bony orbit; it first runs outwards and backwards, then curves upwards and backwards, and is inserted by a broad, short tendon into the sclerotica, near the insertion of the superior oblique. The superior rectus muscle is above, the inferior beneath the eye; the internal at the nasal, and the external at the temporal side of the globe.

The muscles of the eye are connected with the brain by the third, fourth, and sixth cerebral nerves, by branches of the fifth, and the sympathetic. The third nerve passes to the superior, inferior, and internal recti, and to the inferior oblique muscles. The fourth nerve supplies the superior oblique. The sixth nerve supplies the external rectus.

The eye rotates in the orbit like a ball in a socket; that is, it has a certain fixed point around which all of the movements take place; this point is called the *centre of rotation*, and is situated on the ocular axis about 1.77 *mm.* behind its middle. The eye, in its movements, has also a twisting motion around the ocular axis, like a wheel turned to and fro on an axle. This causes an inclination of the vertical meridian, and a corresponding change in the positions of the other meridians.

The eyes are in a *primary* position when, the head being erect, they are directed to the horizon; all other positions are regarded as *secondary*.

The *vertical meridian* is the longest vertical circle drawn perpendicular to the equator when the eye is in a primary position.

The *horizontal* meridian is perpendicular to this. The vertical and horizontal meridians divide the retina into four equal imaginary parts, called *quadrants;* these may again be subdivided. "The vertical and horizontal meridians or separating lines of the two retinas are generally nearly the same, with imaginary perpendicular and horizontal sections through the middle of the retina, in the primary position of the eye. Yet, even this is not quite exact, since slight deviations almost always exist. (*Recklinghausen*, *Hering*, *Volkman.*) We therefore do well to invert the definition, as it were, and to designate those meridians as horizontal or oblique which have their common visual direction in the visual plane, or, as the case may be, a plane perpendicular to this." (*Stellwag.*)

The direction in which a muscle acts may be ascertained by drawing a straight line between the middle of its origin and

insertion; the plane of the muscle is one drawn through this line and the central point of rotation of the eye. A line perpendicular to this plane, passing through the point of rotation, is called the axis of turning.

The vertical meridian assumes degrees of inclinations varying with the different movements of the eye, but, from habit, we see vertical objects in their natural position even when the vertical meridian is inclined. Donders laid down the following rules as to the position of the vertical meridian in the different movements of the eye:

"1. In looking in the horizontal meridian-plane, straightforwards, to the right or to the left, the vertical meridian suffers no inclination, but remains vertical.

"2. In looking in the vertical meridian-plane, straightforwards, upwards, or downwards, the vertical meridian also remains vertical.

"3. In looking diagonally upwards to the left, the vertical meridians of both eyes are inclined parallelly to the left.

"4. In looking diagonally downwards to the left, the vertical meridians of both eyes are inclined parallelly to the right.

"5. In looking diagonally upwards to the right, the vertical meridians of both eyes are inclined parallelly to the right.

"6. In looking diagonally downwards to the right, the vertical meridians of both eyes are inclined parallelly to the left."

The superior rectus muscle moves the eye from the primary position upwards and a little inwards, and inclines the vertical meridian inwards. The inferior rectus moves the eye downwards and inwards, and inclines the vertical meridian outwards.

The internal rectus turns the eye directly inwards; the external rectus directly outwards; neither produces any inclination of the vertical meridian.

The tendency of the four recti muscles acting together, is to draw the eye into the orbit. The superior oblique muscle turns the eye downwards and outwards, and inclines the vertical meridian inwards.

The inferior oblique turns the eye upwards and outwards, and inclines the vertical meridian outwards.

The simultaneous action of the two oblique muscles, is to draw the eye out of the orbit; hence, they are in this respect antagonistic to the four recti muscles.

The following is a tabular arrangement of the different movements of the eye, produced by the single, double, or triple action of the external ocular muscles:

Movement	*Is produced by the action of the*
Upwards	Superior rectus and inferior oblique.
Downwards	Inferior rectus and superior oblique.
Inwards	Internal rectus.
Outwards	External rectus.
Upwards and inwards	Superior rectus, internal rectus, and inferior oblique.
Upwards and outwards	Superior rectus, external rectus, and inferior oblique.
Downwards and inwards	Inferior rectus, internal rectus, and superior oblique.
Downwards and outwards	Inferior rectus, external rectus, and superior oblique. (*Wells.*)

By means of the six above-described muscles, the eye may be rotated around any axis passing through the centre of motion. The rotation can extend horizontally about 87°; perpendicularly, from 86° to 100°. The motion is greater inwards than outwards, and greater downwards than upwards. As relates to the movements of the eye, the centre of motion forms a fixed point; and, in normal vision, the two eyes are always placed in such positions that they fix on one and the same point, called the point of fixation. The line of gaze, or look, is a straight one passing from the point of fixation to the centre of rotation; this line differs from the visual line, which corresponds with the unrefracted ray that passes to the temporal side of the centre of rotation; but the difference between the two lines is so slight that, in most cases, it need not be taken into consideration. (*Helmholtz.*)

The *base line* is a straight one drawn between the points

of rotation of both eyes. The *median plane* is one passing through the vertical axes of the head and through the middle of the base line.

The visual plane is a plane passing through the visual lines and through the point of fixation. The plane of fixed gaze (*Blickebene*, *Plan de Regard*) passes through the point of fixation and the centre of rotation of both eyes, hence it differs slightly from the visual plane.

The median line is the line of intersection between the median plane and the plane of gaze. When the muscles of both eyes are at rest, the visual lines converge to a point 8″ or 12″ distant in front, and the angle of convergence is called the *muscular mesoropter*.

There is always an increased tendency to convergence when the eyes are looking downwards, and an increased tendency to divergence when they are looking upwards.

In binocular vision there are two kinds of movements, viz., associative and accommodative. In the latter the visual lines converge to the point of fixation, and the external muscles are most intimately associated with those of the irides and of accommodation. With every enlargement of the angle of convergence there is a corresponding simultaneous contraction of the pupil and increase in the refraction; with every diminution in the angle of convergence there is a corresponding enlargement of the pupil and diminution of the refraction.

In the ordinary exercise of our eyes, we make them move in the orbits so as to successively fix the different points of the objects looked at, in order that we may simultaneously receive on the centres of the two retinas the images of each point respectively.

There is no natural divergence of the visual lines. Planes passing through the vertical meridians of the two eyes, when they are in a primary position, slightly converge downwards and diverge upwards.

The Law of Identical Retinal Points.

The explanation of the phenomena of single vision resulting from two retinal images — one in each eye — has given rise to much investigation and discussion among physiologists. Johannes Müller laid it down as a law that, "For each point of one retina there is on the other a corresponding point;" hence, when each of a pair of these identical points is simultaneously excited, but a single sensation is produced in the brain.

The corresponding points in each retina (without noticing slight deviations), are those which are situated at the same lateral and vertical distances from the point of the retina at which the rays of light come to a focus when we fix the eye for exact vision, namely, the yellow spot. (*Helmholtz.*)

In binocular vision, as before stated, the outward projection is in the common visual line that divides the angle of convergence into two equal parts, and the eccentric retinal images are arranged around this in accordance with fixed laws. The retinal horizon corresponds with the plane of gaze when the eyes are in a primary position. Objects, whose images are formed on the vertical lines, passing through the fovea centralis and dividing the horizons of the two retinas, appear in the median plane, or in a plane perpendicular to the visual plane drawn through the common visual axis; these lines are said to be identical meridians. Other meridians are identical which lie in corresponding planes passing through the common visual axis. We see in the same direction all points of objects whose images are formed on corresponding parts of the two retinas. The point of fixation is called the *nuclear-point* of visual space; and an imaginary plane passing through the nuclear-point perpendicular to the visual direction is called the *nuclear-surface* of the visual space. A line or surface in the nuclear-space, all of whose points are formed on corresponding points of the two retinas, is called the *horopter*.

It is evident that this law of identical points cannot apply to eccentric vision, for here the images in either eye must be formed to the right or left of the vertical meridian passing through the yellow spot, and yet they are seen single. "We may also say that the power of the single sensation extends to different parts of both retinas, and may be here called *facultative*, since practice and all kinds of artificial assistances cause an object originally seen single, to appear separated into two false images. Still more, single vision with disconsonant-retinal positions is one of the requirements for the solid vision of objects. (*Hering.*)" (*Stellwag.*)

There are certain phenomena which militate against the doctrine of absolute identity of corresponding points; as, for instance, if we form two circles of different magnitudes, situated near each other, and adjust the eyes, either by convergence or by means of the stereoscope, so that the lines coincide in the yellow spots, we see but a single circle, whose magnitude is a mean between the two looked at. With a single eye, if the smaller circle be drawn within the larger, under all conditions of adjustment and position, two circles are seen instead of one of medium magnitude. Some have thought it probable, from pathological investigations, that the nerve fibres from the right halves of each retina pass to the right cerebral hemisphere, and those from the left halves pass to the left side of the brain. Tyndall gives a familiar illustration of this: "We may compare the arrangement to that of the reins of a pair of horses: the inner fibres only of each optic nerve cross, so that those which run to the right half of the brain are the outer fibres of the right, and the inner fibres of the left retina, while those which run to the left cerebral hemisphere are the outer fibres of the left, and the inner of the right retina: just as the inner reins of both horses cross, so that the rein of the off-horse and the inner of the near one run together to the driver's right hand, while the inner rein of the off, and the outer of the near horse pass to his left hand."

But this arrangement of the nerve fibres has been doubted by many eminent anatomists; and the more recent investigations of Biesiadecki, Pawlowsky, Michel, Mandelstamm, and Scheel seem to prove that the optic tracts totally cross each other in the chiasma.

The explanation of the phenomenon of single vision from two retinal images is still very unsatisfactory. Müller's hypothesis of identical retinal points is rejected by many eminent physiologists. It is often difficult to distinguish, among the ideas acquired by the sense of sight, between that which proceeds immediately from sensation and that which proceeds, on the contrary, from experience and practice. Hence, one class of observers is disposed to assign the larger place to the influence of experience, and from it to deduce all ideas of space. This may be called the *empirical* theory. Others, while constrained to admit the influence of experience as to some perceptions, believe themselves obliged to maintain, as to certain elementary perceptions, which are presented in the same manner to all observers, a system of innate or inherent ideas not based upon experience. This theory, in opposition to the preceding, we may designate the *innate* theory of visual perceptions. Helmholtz concludes, "That every anatomical hypothesis which admits a complete fusion in the sensations of the two sides, by supposing that the fibres proceeding from corresponding retinal points reunite two by two in fibres which transmit each a single sensation to the brain, ought to be abandoned as not in accord with the facts. . . . . . In truth, it seems to me that, for an explanation altogether satisfactory, no such hypothesis is needed."

Estimation of Depth and Solidity.

When we look at an irregularly formed object, or one whose visible surface is not plane, a plane image is formed in both eyes; but certain parts of the object are visible to either eye that are not seen by the other. It is these parts of the image visible to one eye alone, and not to the other,

that give the idea of solidity of objects, or of three dimensions. If we take a flat ruler and hold the square edge before the eyes, in the median plane, the flat edge is seen alike by either eye, but the right side of the ruler is visible to the right eye alone, the other side to the left alone; here we have an image common to both eyes and an additional one for each eye separately. From the additional image to the right eye, we see that the ruler has a side; thus we find that it has two dimensions; and we judge the size of the side by comparing its image with the image of the flat edge, formed alike in both eyes. So with the left-hand side — its image is formed alone on the left half of the retina of the left eye, from which we derive the idea that the ruler has another side; thus, by these images, one common to both eyes, the others different from each other, and each respectively belonging to a single eye, we learn that the ruler has a flat edge and two sides; and so with all solid objects seen in binocular vision, those parts of images not lying in the clear nuclear-space common to both eyes — that is, in the surface seen alike by either eye — give the perception of depth and solidity. This mode of determining the solidity of bodies does not so well apply to objects situated at great distances, for in such cases the images formed on the two retinas are very nearly alike. Here we are greatly assisted in our estimate of solidity, by what we have learned from past experience as to the particular nature of the objects which we see; for example, when we see the mast of a ship at the distance of two or three miles, we imagine it to be solid and round, because we have previously learned that such is the usual form of masts; but if a plane surface, equal to the width of the mast, were placed by the side of the latter, we could scarcely distinguish between the two.

Ocular Estimation of Magnitude and Distance.

The faculty which we possess of determining with more or less accuracy the form, size, distances, and relative posi-

tions of objects situated in space, is an acquired one; it is the result of knowledge gained by experience. Observations on those born blind, and who after some years have been restored to sight, show that such persons can at first form by ocular estimation no ideas of the magnitude and distance of objects—that they have to go through the same processes of learning by slow degrees as the child. Young children often make ludicrous mistakes in perspective estimation, and reach out their hands to grasp objects that are far beyond their reach.

Helmholtz says he distinctly remembers that, when a child, in passing a church in Potsdam, he saw persons standing on the platform of the tower. From their apparently diminutive size, he took them for toys, and asked his mother to give them to him, believing that he had only to reach out his hand in order to grasp them, because perspective made the persons appear too small. Who, even in riper years, has not momentarily thought that he saw a speck on the glass, but soon discovered that the illusion was caused by a large bird flying in the distance.

In order to obtain an accurate knowledge of the real positions of objects in space, it is necessary to know, on the line of vision, the distance from the eye of each of the points which we see. The same object, at different distances, gives images of magnitudes, varying with the size of the visual angle under which it is seen; objects of known form and size placed by the side of those whose magnitudes and distances are unknown, enable us to determine with accuracy the distance and magnitude of the latter. The military make use of perspective in calculating the distance and position of the enemy when on unknown ground. Optical instruments for this purpose have been constructed, by means of which the angle under which a man is seen is accurately determined and recorded; and a corresponding distance at once read off. Trees, houses, and cultivated plants, are

much less useful for these determinations, on account of the greater variations of their size.

The size of the retinal image is inversely proportional to the distance of the object. If we look with one eye at the trunk of a large tree, distant one hundred feet, and hold in the hand vertically a cane, at a certain distance from the eye, the cane just covers the trunk of the tree, and prevents the latter from being seen. The retinal image of the cane has the same breadth as that of the tree; hence, the judgment must be brought into action to determine the distance of the tree. Our experience has previously taught us that if the tree were very small, and as near the eye as the cane, we could not see the ground on which it stands, nor its branches and foliage; hence, we conclude that it is larger, and at a greater distance, because the ground and other parts of the tree than its trunk appear in the field of vision. We define accurately the shape of the leaves, also the roughness and irregularities of the bark, which we know we could not see at the distance of two or three hundred feet; hence, we conclude that the tree is nearer than the latter distance and farther off than the cane; the tree may stand just across a street or lot of known width, or by the side of objects, the distance and size of which we have previously learned. The brain compares the new sensation from the retinal image of the tree with those from other objects previously defined, estimated, and stored away in the memory, and thus, by comparison, we form a tolerably accurate judgment of the distance of the tree, and knowing the distance, we estimate its size. The case is different when we look with one eye, through a tube the length of which we do not know, or sit at the back of a room and look through an open shutter at objects of unknown distance and magnitude; here, surrounding bodies of known form and distance are excluded from the field of vision; we now find it very difficult to correctly estimate distance, particularly of flat surfaces. For irregular bodies, the angles formed by one side, compared with those of the

plane surfaces, materially assist our powers of forming a correct judgment, particularly if a little time be allowed to move the visual line, so as to bear on different parts of the object or objects in the field of vision. The tension of accommodation assists us very materially in determining size and distance, because we are accustomed to exercise a certain amount for every specified distance nearer than twenty feet. If, through a tube placed in a screen, or a partition wall, so as to prevent our seeing any object except the point looked at, we can read No. 1 Snellen Test-Type, at 5″ or 6″, we judge it to be very near the eye, because a high tension of the ciliary muscle is required. We have learned by past experience that for each distance there is a corresponding tension of accommodation, and when that distance is unknown, we unconsciously measure it and the magnitude of the object by the amount of innervation required to produce the necessary tension of the ciliary muscles. We also, in order to assist our judgment of distances, move the head or body, so as to see objects under different angles, and thus form a parallax.

Persons with but one eye perform delicate manipulations slowly and hesitatingly, and are liable to commit errors of judgment. Those who have recently lost an eye, soon learn this by experience. In attempting, for illustration, to pour water from a pitcher into a goblet, they often miss the glass. Any one can easily appreciate the difficulties such persons experience in correctly estimating the distance and position of objects, by taking in his hand a pencil, and, after closing one eye, attempting to quickly place the point, held vertically, on a small spot on a table. He will in most of his efforts fail in the attempt, but if his hand be moved slowly, so as to give him time to correct errors of judgment, the point of the pencil will fall on the designated spot. With a single eye, we can accomplish very good and useful results, but with two, our judgment is more quickly formed, and with a much greater degree of accuracy. Convergence and accommoda-

tion always act in perfect harmony. If the refractive media are adjusted for a point six inches from the eyes, the internal recti muscles converge the visual axes to that point. If the accommodation be for two, four, six, or twenty feet, there is always a corresponding degree of convergence; hence, with two eyes there are two separate and distinct sensations brought into action — one, measured by the amount of nervous power required to produce a definite degree of contraction of the ciliary muscles, the other, of the internal recti muscles. With the exercise of both of these acts brought into use in binocular vision, in addition to other means, we are enabled to estimate distance and magnitude with a wonderful degree of accuracy. We march boldly up to the very brink of a precipice, or leap a chasm in perfect safety, when the miscalculation of a few inches in its width would lead us to inevitable destruction. The skilled acrobat, when springing from one cross-bar to another, suspended fifty feet in the air, stakes his life on the accuracy of his judgment of distances of ten, fifteen, or twenty feet, almost to within the fraction of an inch. It is doubtful if he could with safety accomplish these feats with but a single eye. With two eyes we get an idea of another side of solid objects, and of another series of angles for comparison with those from the other surfaces. With two eyes we measure the amount of obstruction on the background produced by an object — as, if we look with one eye at a lamp-post in front of the wall of a house, we find that the post obstructs the view of a certain part of the wall; if we close that eye and look with the other, a certain other part of the wall is hidden from view. Now, we unconsciously measure the size of the angles forming the images, not only of the part of the wall obstructed by the post common to both eyes, but also make separate measurement by each eye of the obstructed part of the retinal image belonging to each respectively. We know that the part of the house obstructed from view and the post are inclosed in the same angle, and knowing the size of the post, we instantly calcu-

late the distance it must be from the house in order that the angle may cover that part hidden from view. On the contrary, knowing the distance of the house, and the dimensions of the surface hidden, we reciprocally estimate the size of the post and its distance from the eyes; and so for all other objects within the field of vision. The angles of each object forming perspective images on the retina, are estimated, compared, and their relative size and positions determined, almost instantaneously, and with a wonderful degree of accuracy. If the field of vision be large, or if we desire to test the correctness of the judgment formed by a single glance, we rapidly bring the visual lines to bear successively on different parts of the visual field, and then compare the perspective retinal images as they appear at the different points of fixation; thus we arrive at most astonishingly correct conclusions in regard to the size and distance of objects and their relative positions to each other. Everybody with serviceable eyes is exercising them from infancy to old age. They know the magnitude, color, distance, and relative position of every object in the visual field, because they see them; but how few ever stop to analyze the psychological processes the brain almost instantaneously goes through in order to arrive at these definite and certain conclusions — all the result of knowledge gained by experience.

Aerial Perspective.

Illumination furnishes us with another means of appreciating distance, particularly of remote objects. By *aerial perspective* is understood the partial obscurities and changes of color which the images of distant objects undergo from the more or less incomplete transparency of the layers of atmosphere through which they are seen. Water that is suspended in the air in the form of fogs, which are usually superimposed over low grounds and lakes, appears blue when illuminated in front of a dark back-ground, and gives a red color to light traversing it from a luminous source. The greater the ob-

scurity of the atmosphere between the eyes of the observer and distant objects, the greater is the modification that the colors of these objects undergo. It will be in blue if the objects are darker, or in red if they are brighter than the intervening obscuration. This is the reason why distant mountains appear blue and the setting sun appears red: so the clouds near the horizon are ordinarily blue, but when the sun shines through them they appear red. Distant objects seen through a misty or smoky atmosphere seem much farther off than when looked at through a clear stratum of air; thus, mountains viewed from a plain seem much more distant than when seen from the top of an elevation equally remote, because in the former case they are seen through a misty stratum of air that generally rests over low grounds, while in the latter case the observer is above the layer that partially obstructs the view.

It is very difficult to correctly estimate the distance of a mountain, partially hidden from view by another; so with a single hill or knob abruptly rising from a plain; here, there are no surrounding objects of known form and magnitude to aid us, by comparison, in forming our judgment; and our estimation of the size and distance varies with the transparency of the atmosphere.

The painter utilizes aerial perspective in order to present to us, upon canvas, representations of objects of three dimensions, particularly of those situated at a distance. He first gives the perspective outlines of the plain surfaces of bodies, then adds a second side; afterwards, by the proper distribution of lights and shades, he adds the representation of another dimension, thus giving to the images of the objects the appearance of depth and solidity. Bodies of different magnitudes and distances are represented in perspective as they would appear to the eyes when actually looking at them. He is thus enabled, within certain limits, to produce on the flat surface of the canvas very striking illusions, which present to both eyes the same image. He enlarges

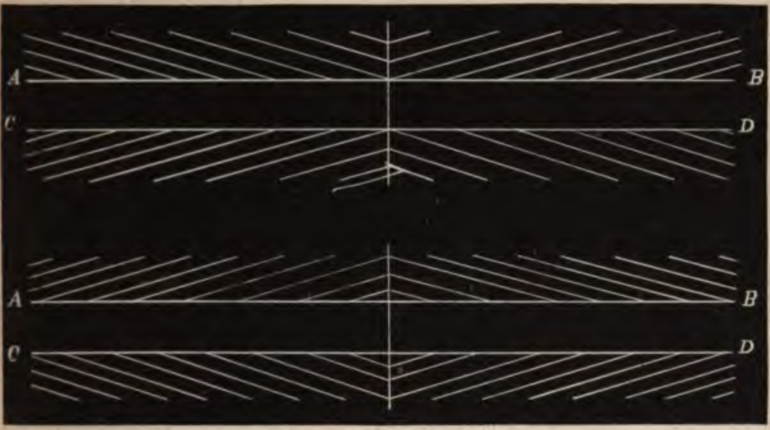
these limits by other means. The landscape is usually represented as it appears when the sun is low in the horizon, giving strong shadows, thus making the perspective outlines of objects stand out in bold relief, and particularly sharp on the back-ground of the sky. He chooses a misty atmosphere because it makes the objects appear farther off, and their bright surfaces stand out in bolder relief; and, at the same time, obscures the delicate shades, which, owing to his limited supply of colors, he is unable to imitate. He brings objects of known form and size into the field, as men, cattle, houses, etc., in order that the distances, dimensions, and relative positions of the different objects represented may be measured, by comparison, as, by representing a man as he would appear in the distance beside a tree; knowing the ordinary height and size of a man, the observer instantly forms an idea by comparison of the height, size, and distance of the tree, and this enables him to form his judgment of the magnitude and position of other objects; for illustration, if a man were standing at the foot of a tree, situated on the side of a mountain, judging the height and distance of the tree by the image of the man, the observer estimates the height and distance of the mountain by comparing it with that of the tree. Houses are introduced into paintings because the angles forming them are known to be regular, and particularly enable us to recognize the horizontal position of surfaces. With all of these means of illusion the painter can produce wonderful results. "But objects of unknown and irregular shape, as rocks or masses of ice, baffle the skill of the most consummate artists; and even their representations in the most complete and perfect manner possible, by means of photography, often show nothing but a confused mass of black and white. Yet, when we have these objects in reality before our eyes, a single glance is enough for us to recognize the form." (*Helmholtz.*)

Illusions of Ocular Estimation.

There are many errors of ocular estimation, dependent upon the nature of the eye, which it is difficult for the judgment to correct. If two lines of equal length be drawn near each other, one vertical the other horizontal, we usually judge the horizontal one to be the longer of the two; for this reason, if we attempt by the eye, to draw a square figure on a piece of paper placed perpendicular to the line of vision, we always make the vertical side too short. If a vertical line be cut by a horizontal one, and the surface be held perpendicular to the visual line at the point of crossing, to most persons, when using the right eye alone, the right angles to the right and above, and to the left and below the horizontal line, will appear to be obtuse angles, while those opposite will appear to be acute. If the left eye be used, just the reverse takes place. If we attempt to draw, when looking with the right eye, on a piece of paper held perpendicular to the visual line, a perpendicular to a horizontal line, the top will incline about 1° to the right; and all of the angles will appear as right angles. If the effort be made by aid of the left eye, the top of the line will incline about 1° to the left; and the four angles will be estimated as rectangles. In a correctly drawn equilateral triangle, the angle at the top will appear smaller than those at the base. The illusion in the estimation of right angles is probably due to a slight inclination of the retinal horizon with reference to the visual plane, together with a corresponding inclination of the vertical meridian. A line divided by several cross lines, appears longer than an undivided one of equal length. Bravais states that, when one is on the sea, at a certain distance from a coast which presents great irregularities of surface, and makes a design of the elevations as they present themselves to the eye, the horizontal dimensions having been correctly drawn according to a certain scale, the angular vertical distances are always represented on a scale twice as large. An amusing parlor experiment is often made; a hat is shown a

person, and he is requested to designate on the wall a point he thinks the hat will reach when placed on the floor; he invariably estimates the height too great by about one-half.

If parallel lines be drawn, as A B and C D, in Figures 54 and 55, they appear to us as parallel; but if short oblique



Figures 54 and 55.

lines be added, as represented in Figure 54, the parallel lines seem to converge from their middles; but if the oblique lines be drawn as in Figure 55, the parallel lines seem to diverge from their middles. If the skirt of a lady's dress be vertically striped, she appears taller than she is in reality; the effect is reversed if the stripes are horizontal. Tailors and modistes make practical application of the various means of producing ocular illusions, in order to hide the real or imaginary deformities of the human figure.

The Stereoscope.

There is in each eye a perspective image of objects situated in the field of vision, and as the two eyes do not occupy the same position in space, they regard these objects from different points of view; consequently, the projected perspective images are not exactly alike. When we hold a

thin book in the median plane, with its edge towards the face, the right eye sees the edge and the right side, the left eye the edge and the left side of the book — the most distant part of the right side appears to the right eye to the right of the nearest part, while the farthest part of the left side appears to the left eye to the left of the nearest part. If a painting be made, or a photographic representation be taken of the book, only the edge and one side will be represented; and the eyes, in looking at the picture, will receive a like image in both; the imagination must be strongly exercised in order to obtain an idea of solidity or three dimensions. If two photographic instruments be placed a little apart, corresponding to, or a little more than the distance between the two eyes, and a picture of the same solid object be taken by each, that of the right-hand instrument will represent the image as it is formed on the retina of the right eye, the left-hand instrument the image on the retina of the left eye. Now, if the right-hand photograph be placed to the right by the side of the left-hand one, any person who has a sufficient command over the internal recti muscles to bring corresponding points of the two images to be seen singly with both eyes, will have the same sensorial impressions, in black and white, as if he were actually looking at the object itself. Any one with two serviceable eyes can easily prove by experiment, his ability to fuse, by convergence, two similar images formed by two like plane objects. Figure 56 repre-

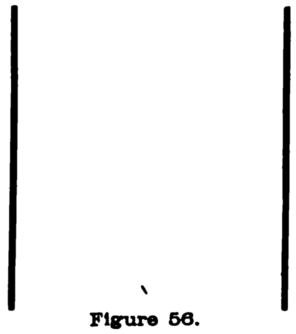


Figure 56.

sents two lines that are parallel and alike in every respect; when we look at them in the ordinary exercise of vision we see the two lines, but if the eyes be sufficiently converged to cause both images to fall on identical meridians of the two retinas, but a single line will be seen, situated intermediate between the two. The necessary degree of convergence is more easily produced if the page be placed vertically, at the distance of two or three feet, and the point of a pen be held ten or twelve inches from the eyes, in the common visual line directed to a point intermediate between the two lines. If we look sharply at the point of the pen we shall at first see three lines, but soon the two side lines will disappear, and a single one intermediate between the two will be seen; the images are now formed on identical meridians, and the sensation of a single image produced.

The circles represented in Figure 57 can be fused in the same manner. So in all stereoscopic pictures, corre-

Figure 57.

sponding symmetrical points and lines of the photographs can, by convergence of the two eyes, be reproduced on identical parts of the two retinas and seen singly; while the non-symmetrical parts of the pictures are reproduced only in the eye to which they respectively belong and give the impression of depth and solidity, making solid objects stand out in bold relief. The symmetrical parts of the photographs are fused much more easily by the aid of the stereoscope, and the effect is the same as if produced by convergence. The original ster-

eoscope of Wheatstone was made by placing two plane mirrors in such positions that the reflected images of symmetrical points of the photographs appeared on identical points of the two retinas. In the stereoscope of Brewster, now in common use, the same effect is produced by placing two prisms having the proper angles, before the eyes, with their bases outwards. The rays of light emanating from different points of the two photographs are so bent by the prisms, that, by very slight assistance from the external ocular muscles, they are fused so as to give the impression of a single image.

The prisms are usually combined with convex lenses, in order to magnify the images, and thus render them more distinct. Brewster's instrument is the most convenient, but the illusion is rendered more perfect by the reflecting stereoscope of Wheatstone. The perfection of the illusion produced by the stereoscope cannot fail to excite our wonder and admiration. If two cards be printed from the same type, or from an engraved plate, the two impressions must be exactly alike; and if placed side by side in a stereoscope, they are easily united into a single flat image. The most skilful engraver cannot make an exact copy of an engraved plate; consequently, if an impression from the original, and one from the copy, be placed in the stereoscope, the eye instantly detects the difference, and this trial forms one of the most certain means of detecting counterfeit bank-notes. If a genuine note and a spurious one be examined in this manner, the difference between the two at once becomes plainly manifest. To fuse symmetrical points of stereoscopic pictures, the eyes undergo the same changes of convergence as they would in looking at the actual objects themselves.

The Pseudoscope.

By means of an instrument called the Pseudoscope, a modification is made in the binocular images of solid objects, causing the stereoscopic relief to be reversed, so that convex

surfaces appear concave, and concave surfaces convex. This effect can be produced by two plane mirrors, one placed by the side of each eye, in such a position as to cause the rays of light coming from different parts of a solid object, to laterally cross each other before entering the eyes; but the illusion is much more perfectly rendered by the pseudoscope of Wheatstone, which contains two rectangular glass prisms, so arranged that the unrefracted rays pass to the eyes of the observer in a direction parallel to their hypothenuse. The rays corresponding with the visual axes remain unchanged; but all other rays, to the right of the median plane, in the right eye, and to the left of the median plane, in the left eye, fall on the hypothenuse at acute angles and are totally reflected; rays from two points of the object cross each other before entering the eyes, rendering the convergence greater for the distant than for the near points; hence, the near points appear farther off than the far points. As each eye sees the objects symmetrically reversed by reflection, the concordance between the images of the two eyes is preserved; if we look through the pseudoscope at the inside of a teacup or bowl, we seem to be looking at the outside; on the contrary, if the convex surfaces be turned towards the eyes we seemingly see them concave. If we look at a medal in relief, we apparently see its mould; so on the contrary, if we look at the mould it appears as the medal in relief.

A partial pseudoscopic effect, or reversal of relief, can be produced by reversing the images in a stereoscope; that is, by placing the image intended for the right eye to the left of the one belonging to the left eye, the right eye sees the non-symmetrical part of the image normally visible to the left eye alone; and the left eye sees the non-symmetrical part of the image belonging to the right eye.

Thus, in the stereoscope, Fig. 57 appears as a truncated wire cone, with base farthest from the eyes. But change the position of the figures, placing that at the right to the left, and then the base will appear nearest the eyes.

PART III.

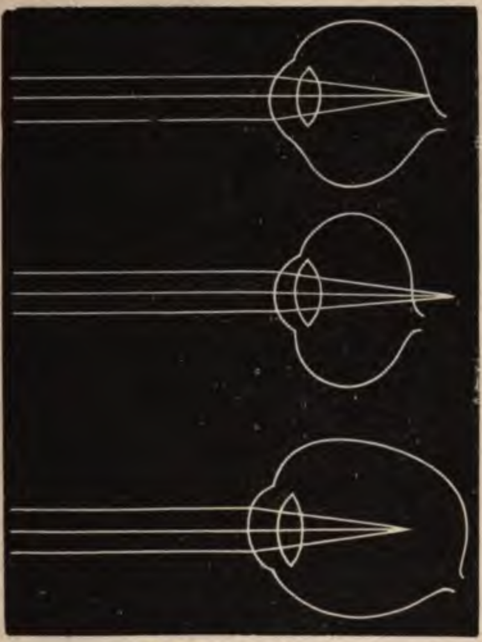
ERRORS OF REFRACTION AND DEFECTS OF ACCOMMODATION.

MOST of what has been said in the second part of this work has reference to the emmetropic eye — that is, to an eye so constructed that, when at rest, or in other words, when there is no active accommodation, parallel rays, or rays emanating from a point twenty feet or more distant, are united in a point on the bacillar layer of the retina. Recent investigations show that the emmetropic eye is only emmetropic in the region of the macula lutea, while it is hypermetropic in all of its other parts, the degree gradually increasing from near the yellow spot to the periphery of the retina. The hypermetropic eye is hypermetropic at the macula lutea, still more so at the lateral parts of the globe. The highest grade of myopia is at or near the yellow spot, while the degree rapidly diminishes as the distance from this position increases. Neither in the emmetropic nor in the ametropic eye, is the distance of the retina from the optical centre of the eye the same in all its parts. The emmetropic eye is taken as the standard of measurement, by which ametropia and its degree are determined.

The typical forms of the emmetropic, hypermetropic, and myopic eye are represented in Figures 58, 59, and 60, after Donders.

It is seen in Figure 58, representing the emmetropic eye,

that parallel rays unite in exactly the right point to form a perfectly defined image on the sensitive layer of the retina.



Figures 58, 59, 60.

In the hypermetropic eye, Figure 59, the retina is too near the optical centre of the eye; parallel rays are united in a virtual focus behind the retina; consequently, the retinal image is blurred and indistinct. In the myopic eye (Figure 60), parallel rays are brought to a focus in front of the retina; they over-cross and fall on the bacillar layer in circles of diffusion.

Changes that take place in the Eye with the Advance of Age.

It has been shown that the acuteness of vision, particularly for distant objects, varies with the degree of transparency of the atmosphere. The perfection of retinal images

also varies with the degree of transparency of the refractive media. Daily observations with the ophthalmoscope prove to us that at no period of life is the transparency of the media so perfect as in childhood, while it gradually diminishes with age; hence, it follows that even if there were no other causes to produce this effect, the acuteness of vision must be greater in youth than it is in after-life.

The loss of transparency of the media is manifested by diminished lustre of the cornea and the formation of the arcus senilis near its margin; by the formation of folds of the membranes of the vitreous, and by the increase in numbers and size of muscæ volitantes; the layers of the crystalline lens become turbid and its nucleus assumes a yellowish tint; the retina also becomes slightly opaque. The diminution of transparency of the refractive media progresses with such uniform regularity with advancing years, that practised ophthalmoscopists are able to approximate the age of the patient by observing the clearness with which the fundus of the eye can be seen.

Changes take place in the sclerotica, choroid, and iris; the size of the pupil gradually diminishes with increasing years; the quantity of light admitted within the eye is lessened, and this decrease must be compensated for by an increase in the degree of illumination; senile changes take place in the optic nerve, whereby its conductive power is diminished, and it is probable that the sensibility of the perceptive elements is blunted. Other changes occur, causing a decrease in the refraction of the eye, and a lessening of the range of accommodation. The crystalline lens increases in firmness and becomes more homogeneous, while the surfaces of separation between its different layers become less distinctly marked; as a consequence, the crystalline loses a part of its refractive power; the increase in its firmness renders it more difficult for the ciliary muscle to produce the degree of curvature of the surfaces of the lens necessary for the distinct near vision of small objects, thus lessening the range

of accommodation. The gradual diminution in the refraction of the eye when at rest, gives rise, at middle age or a little later, to acquired hypermetropia. Some of the above-mentioned changes commence in childhood, but progress so slowly that they escape notice; the defects being in a great measure neutralized by an increase of illumination, and by holding small objects farther from the eyes, until finally they become sufficiently manifest to interfere with the functions of the unassisted eye.

Range of Accommodation Diminished by Age.

As stated on page 80, *r* represents the farthest point of distinct vision, and *p* the nearest point at which small objects can be distinctly seen; R and P, the measure of these distances from the eye respectively. $\frac{1}{A}$ represents the range of accommodation, and ∞ represents infinite distance. The range of accommodation is found by the formula $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$. *r* represents the natural refractive state of the eye when at rest, and in the emmetropic eye its distance is infinite. This point does not materially change its position until advanced life, generally at the age of seventy or seventy-five years; but *p*, the nearest point of distinct vision, commences to recede at an early period of life. A child ten years of age can ordinarily place a thread in the eye of a cambric needle held two and three-quarter inches from the eye; at the age of fifteen years, the near point recedes to about three and a quarter inches; at twenty, the nearest point for which the eye can accommodate, is about three and three-quarter inches; at twenty-five, it is about four and a quarter inches distant; at thirty, it recedes to four and a half inches; at thirty-five, to six and a half inches; at forty years, the near point has passed to about nine inches from the eye; at forty-five, small print, to be distinctly seen, has to be held at about the distance of twelve inches; at fifty, it is about eighteen inches; at fifty-five, twenty-two inches; at sixty,

from thirty to thirty-six inches; the recession of the near point continues to increase until the age of seventy-five, when the entire remaining powers of accommodation are required to make remote objects distinctly seen. At eighty, there is no distinct vision without the assistance of convex glasses. At the age of forty-five years, emmetropia begins to give way to hypermetropia; the natural refractive powers of the dioptric media slightly diminish, and from about this period of life, a part of the accommodation is required to adjust the eye for distinct vision of distant objects. The acquired hypermetropia gradually increases until at about the age of seventy-five, when, if the ciliary muscle be paralyzed with atropia, it usually requires a lens $+\frac{1}{20}$, to see remote objects distinctly.

With the aid of the accommodation, remote objects are still seen; hence, the range of accommodation is now reduced to $\frac{1}{20}$, and emmetropia has given way to hypermetropia of $\frac{1}{20}$. Thus we see that the range of accommodation which in the child ten years of age, amounted to $\frac{1}{2\frac{3}{4}}$ has gradually decreased to $\frac{1}{20}$. At the age of eighty years, the total hypermetropia amounts to $\frac{1}{76}$ the remaining accommodative power can no longer adjust the eye for distance; the hypermetropia is now absolute.

The question arises, What is the cause of this gradual recession of the near point from childhood to old age, and after middle age of emmetropia giving way to hypermetropia? Before answering the question, we desire to correct a very common error, and one which is still taught in many of the popular treatises on optics which are in use in academical institutions. It is that the diminution in the accommodative power in age is owing to a flattening of the cornea. This opinion was believed and taught by physiologists until the investigations of modern science proved its fallacy. Accurate measurements of the convexity of the cornea made with the ophthalmometer, show that the cornea does not flatten with

age, but that if there be any change it becomes slightly more convex; hence, some other cause must be sought for to explain the changes which take place in all eyes, and which cause the near point to gradually recede from childhood, until finally, emmetropia gives place to hypermetropia. It cannot be from atrophy or diminished power of the ciliary muscle, because in childhood the muscular system has not fully developed; all the muscles act with more force, and are capable of greater endurance, at the age of twenty or twenty-five years than in childhood, and yet at this period of life, the near point of distinct vision has receded from two and three-quarters to three and three-quarter inches. The true cause, then, must be sought in changes which take place in the crystalline lens. In childhood this is soft, and easily yields to action of the ciliary muscle; the line of separation between its layers is strongly marked, and each one is a refractive surface, thus giving the lens a higher refracting power than it would have if these surfaces were less sharply defined. In childhood, the nucleus of the lens is firm, while the density diminishes towards its periphery. The refractive power of the crystalline, increased by the distinct line of separation between its layers, so marked in childhood, added to its softness and elasticity, particularly of its outer layers and peripheral portion, renders it easy for the ciliary muscle to give a high degree of convexity to its surfaces, and thus to bring p very near the eye. With the advance of age, the outer layers increase in firmness; they gradually approach to the consistency of the nucleus, while the laminated structure becomes less and less distinctly marked, both causes acting to diminish the refractive power of the lens. Its increasing firmness renders it less yielding to the action of the muscle of accommodation; consequently, the same degree of applied muscular force produces less effect in the firmer and more uniformly homogeneous crystalline. In adult age, even if the ciliary muscle could give the surfaces of the lens the same degree of convexity as in childhood, the near point would still be farther from the eye, owing to the diminished refractive power of the

lens. Senile changes take place in all eyes—the same in myopic and hypermetropic as in emmetropic eyes; but it is not so manifest in myopia, because here, with the diminution of refraction, while the far point recedes from the eye, there is an increase in distance at which objects can be seen; the lessening of the range of accommodation creates no disturbance to near vision, because p remains at a convenient distance from the eye, at least in the medium and higher grades of near-sightedness, ordinarily, for distinct vision of small objects, until a late period of life. "Finally, should the question be proposed, whether E is the most desirable condition: as concerns myself, I should give the preference to a slight degree of M, and I shall subsequently state my reasons for doing so." (*Donders.*) The inconvenience to youth from a slight indistinctness of more remote objects, he thinks, is more than compensated for, by the improved vision of middle and advanced life. "Herein the myopic finds a compensation for what he loses, with reference to the vision of remote objects. The advantage is not small. Up to the sixtieth, or even the seventieth year of our age, not to need spectacles, in order to see accurately whatever comes immediately under our eyes, is a great privilege. This privilege belongs to a M of from $\frac{1}{10}$ to $\frac{1}{14}$, in which the eye is not threatened with any special dangers. With slighter degrees of M a good deal of this privilege is still enjoyed. This is a condition which may well be envied by emmetropic eyes. I never found a normal eye which participated in the same advantage. Many persons, however, suppose they are so highly privileged. Almost daily it occurs that at fifty-five years of age the distance of p lies at only from 8″ to 10″, and spectacles are not thought of. Such people consider themselves a lucky exception. They are extremely proud of their sharp sight. The inquiry whether they are near-sighted is answered in the negative, with a smile of self-complacency. At a distance of twenty feet hang Snellen's letter-tests; XX and XXX they do not recognize; XL not at all, or scarcely; L and

LX are the first which are easily recognizable to them. Not until they try glasses of — $\frac{1}{30}$ or — $\frac{1}{30}$ do they well distinguish XX, or at least XXX, with accurate contours. Reluctantly they acknowledge themselves beaten." (*Donders.*) We have given the above extract because so many persons are met with who read fine print without convex glasses at fifty or sixty years of age, and who regard it as an evidence that their eyes have escaped the customary senile changes. Such persons were myopic in youth, although they were probably unaware of the fact. Persons frequently discover that their eyes are near-sighted, by accidentally trying on a pair of concave spectacles, and are surprised to find that distant vision is greatly improved. We often hear the question asked, if any one can see at a distance as clearly as they do after having placed before their eyes a pair of concave spectacles; a new world seems opened to them. It often occurs in the practice of ophthalmic surgery, that in ascertaining the refractive state of the eyes of a patient by means of the test-types hanging twenty feet distant, a person sitting by expresses astonishment that the patient is able to read No. XX at twenty feet. Ask him if he is near-sighted; he says no —he can see as far as any one. Place him in the chair of the patient and give him concave glasses of $\frac{1}{20}$ or $\frac{1}{30}$, and he reads the type with ease. He learns for the first time that he is near-sighted. At fifty-five or sixty years of age he will read small print at 8″ or 10″ from the eye without the assistance of convex glasses, and had he not accidentally found himself myopic, would have thought that his eyes had escaped the usual senile changes.

As the gradual recession of the near point with the advance of age is caused by natural changes taking place in all eyes, the question arises, What point shall be regarded as the commencement of presbyopia? The answer is purely arbitrary. Donders has made it at 8″; and by universal consent, when the recession of p is beyond 8″, the eye is regarded as presbyopic, and in measuring its degrees, $\frac{1}{8}$ is made the starting-point, and in the adjustment of convex glasses, those

are selected which brings p back to 8″ from the eyes. For illustration, if p be 12 inches, then, $\frac{1}{8} - \frac{1}{12} =$ the degree of presbyopia $= \frac{1}{24}$. A glass of $\frac{1}{24}$ placed before the eye brings the near point back to $\frac{1}{8}$, and the eye sees minute objects again at 8″ distant. The term *presbyopia* is restricted to the diminution of the range of accommodation caused by recession of the near point, resulting from senile changes, interfering with the sharpness of vision for near small objects. When a person with emmetropic eyes arrives at the age of about thirty-five years, he seeks, of choice, for reading, print a little larger than he would have done five or ten years previously, and he holds the book a little farther from the eyes, and seeks a stronger light. The difference, however, is so slight, and the change has been so gradual, that it has escaped his notice. At forty, it becomes more perceptible; he begins to be conscious that he cannot see small objects in a dim light quite as well as formerly, but still he gets along very well and suffers but little inconvenience; at forty-five he finds that he has trouble in reading ordinary sized print by artificial light. In writing, he does not keep accurately on the pale ruled lines. Letters like *n* and *u* are not sharply defined; he throws the head back and holds the book at arm's length. The visual angle under which the letters are seen is greatly diminished; consequently, the retinal images are smaller, impressing fewer of the rods and cones of the retina; he seeks a very strong light, not so much to increase the brightness of the retinal image, as to contract the pupil and shut out the peripheral rays, that now produce greater spherical aberration, owing to the fact that the density of the peripheral portion of the lens has more nearly approximated that of its nucleus. We know that in glass lenses all parts are of uniform density, and that the spherical aberration is so great that only the more central rays are united in a focus, the circumferential rays meeting at a shorter distance on its axis; hence, in the construction of optical instruments, a diaphragm having a central perforation is interposed to shut out the peripheral rays which would

form circles of diffusion, and thus disturb the sharpness of the image. In childhood and youth, the crystalline lens diminishes in density from its centre to its circumference; consequently, the peripheral rays are less refracted than they would be if all parts of the lens were of a uniform density. Hence, the circumferential are united at nearly the same point as the central rays; consequently, the child can have a very large pupil, and the peripheral rays still be united in the focus of the central ones. With the increase of the density of the outer layers and decrease in the distinctness of the laminated structure, the focus is thrown farther backwards, and the spherical aberration is increased: the former is overcome by holding the object at a greater distance; the latter, by exposing the eye to a strong light, so as to contract the pupil, and thus shut out the more peripheral rays. In good daylight the presbyope still sees very well, but he instinctively avoids very small print. In the course of a few months, however, he has trouble even in the daytime in distinctly seeing small objects, and the effort becomes painful. He is now conscious, and willing to admit, that his eyes are failing him. He has well-marked presbyopia. We use the term *willing to admit*, because a great many persons take a pride in boasting that they have arrived at middle-age and still have undiminished acuteness of vision; they persuade themselves into the belief that their bodily vigor is so great that senile changes cannot affect them, and only acknowledge their mistaken views when actually compelled to do so, by being no longer able to read, write, or do fine work with the unassisted eyes. From this time the indistinctness of vision of small objects rapidly increases, and in the course of four or five years, distant vision is not quite as good as in earlier life; the crystalline lens, in addition to its increased firmness and more uniform consistency, becomes flatter; the focus of parallel rays during rest of accommodation falls behind the retina; emmetropia has given place to acquired hypermetropia; vision, however, still

remains sufficiently good for distance, so that any deficiency is scarcely noticed; but if, by chance, the person puts on very weak convex glasses, as $\frac{1}{72}$, for instance, he finds the details of the images of distant objects more distinct, and the contours a little more sharply defined.

Presbyopia, in the naturally hypermetropic eye, commences at an earlier period of life, and is usually accompanied by symptoms of muscular fatigue, and nervous and vascular irritation. (Accommodative Asthenopia.)

Presbyopia may also occur in the myopic or near-sighted eye, if the myopia be not of too high a grade; for if the near point recedes from the eye farther than 8″, according to the established rule, it becomes presbyopic, and late in life, when the range of accommodation is greatly diminished, convex glasses may be required for reading and concave for distance.

Treatment of Presbyopia.

Were it not for convex glasses, persons after middle life would have to abandon occupations requiring sharp vision of small objects, and for reading, books would have to be printed in large letters, of a size proportional to the grade of the presbyopia. Fortunately, we have the means of neutralizing the defects in the eyes, caused by senile changes, thus rendering near vision of small objects easy, and sufficiently sharp for practical purposes, until a very advanced period of life. This is accomplished by means of convex glasses, and the principles on which they act have already been explained; they bring the near point back to a convenient distance from the eye, and in absolute hypermetropia they move the focus of the dioptric apparatus forward, so that the image is again formed on the retina, and in old age they are used of sufficient strength to magnify the image so that it covers a larger nerve surface, and thus impresses a greater number of rods and cones, so as in some degree to make up for the blunted sensibility.

In adjusting glasses to the presbyopic eye, several points must be borne in mind.

1st. Owing to the increase in the amount of accommodation, gained by convergence of the visual axes, the binocular near point ($p2$) is nearer the eyes than the monocular p, without convergence; here $\frac{1}{A_2}=\frac{1}{P_2}-\frac{1}{R_2}$ is a greater quantity than $\frac{1}{A}=\frac{1}{P}-\frac{1}{R}$, and glasses that would be suited to a single eye, are too strong for the eyes in binocular vision.

2d. The intimate normal relative associations existing between accommodation and convergence cannot be suddenly changed without producing disturbances to vision, which seriously interfere with the functions of the eyes, as is manifested by nervous and vascular irritation. This is one of the chief causes of the increased sensitiveness to strong light, ciliary and conjunctival hyperæmia, etc., induced by wearing glasses of too high a refractive power.

3d. That the object of convex glasses is not to magnify the retinal images,— exept in extreme old age,— but to bring the near point of distinct vision to a convenient distance from the eyes, and to make objects appear distinct, and as nearly as possible of the size they were before the eyes were presbyopic. They simply supply the loss in power of accommodation and refraction, and when that loss is made up, the object for which the glasses are used is fully accomplished; any attempt to go beyond this produces injurious results. As the result of experience and observations extending over a period of thirty years, we are satisfied that most presbyopic persons who have worn convex spectacles, have seriously injured their eyes by the use of too strong glasses at first; this has created the necessity for changing them soon and often, for those of stronger power.

The habitual use of glasses too strong in the commencement of presbyopia is a most powerful factor in inducing rapid senile changes in the lens and muscles of accommodation. The ciliary muscles are relaxed, and only required to contract to a certain point; they soon become enfeebled, and lose the power to act beyond their accustomed tension; this state of tension soon indicates their maximum strength, which cannot

long be maintained; hence, lenses of higher power must be substituted to relieve the strained accommodation.

Now, this substitution of convex lenses for accommodation from muscular power has a direct influence in increasing, beyond the natural senile changes, the firmness and solidity of the crystalline lens. The latter is of an elastic, jelly-like consistency, that is constantly changing its shape as it is acted upon by opposing forces. In children it is quite soft and supple, but its firmness increases with advancing age, so as to require additional force to produce the same amount of change in its curvatures; the necessity for these changes is lessened just in proportion to the strength of glasses used; consequently, as the motions of its particles on each other are proportionally diminished, they lose their suppleness, become firm, and offer increased resistance to the already enfeebled accommodation. The result is, that strong glasses weaken the muscle of accommodation by diminishing the necessity for its action; this produces an increased firmness of the lens by lessening the motion of its particles on each other, and this in its turn reacts on the muscle, by demanding increased action from its already weakened fibres.

Both of these factors, acting and reacting on each other, cause a rapid increase of the presbyopia and the early commencement of acquired hypermetropia. Now the question arises, What is ordinarily the proper focus of convex glasses suited to one who first notices difficulty in seeing small objects distinctly in dimly lighted apartments or by artificial light?

If the test be made in good daylight, he still can easily read letters printed from pearl type (No. I, Snellen test-letters) at 8″ distant, hence, we might conclude that presbyopia had not yet commenced; but if artificial light be substituted for daylight, the print will be held at 9″ or 10″ as the nearest point at which it can be read. If at 9″, then $\frac{1}{8} - \frac{1}{9} = \frac{1}{72}$. If glasses of 72 inches focus be placed before the eyes, in a great majority of cases, the print will be distinctly seen at 8″ and at 12″ or 14″, the distance at which

print is ordinarily held in reading, and the letters will appear sharply defined, black, and distinct. It is seldom, however, that print from type so small is found in general use. We have in many hundreds of cases prescribed glasses of 72″ focus in the first stages of presbyopia, and have rarely failed to find that they produce all the effect that can be desired, and give perfect satisfaction for at least one or two years. In 1848, M. Sichel, an eminent ophthalmic surgeon of Paris, published a work entitled "Spectacles, their Uses and Abuses," in which he strongly advocated the use of low numbers of glasses in commencing presbyopia; and although much less was then known of the causes of the diminution of refraction and accommodation from senile changes than at the present time, yet his opinions are valuable, because they resulted from practical experience. He says:

"Generally speaking, opticians commence with too powerful numbers, and augment too rapidly their refractive force. Ten years ago they nearly always took No. 48 as their starting point, and patients were soon forced to descend to Nos. 36 and 24. The result was, that it was common to see persons between the age of fifty and sixty years making use of glasses between Nos. 12 and 8, and complaining, as we shall soon explain, that even then they saw but dimly, and that their sight declined from day to day. . . . From the results of my observations, I have taken No. 72 as a point of departure; which number, in general, is suitable for those who have not yet begun to use spectacles, and who assume them at the opportune moment, that is, at the age of forty or a little later. Often, however, especially for those below forty, Nos. 80 and 96 are entirely sufficient during a long time. At first the opticians of Paris deemed the use of too feeble glasses singular, and even ridiculous, regarding them as almost without force. . . . Little by little, they have seen this practice sanctioned by its results. . . . The method of beginning by the highest numbers has now been generally adopted, and I see persons every day to whom the opticians have recom-

mended the use of convex glasses No. 72, and who have been perfectly satisfied with those during several years. It is an error to assert that it is absolutely necessary to change them (the spectacles) from time to time. On the contrary, it is best to change them as rarely as possible; and not at all, if a necessity for doing so is not felt. It is only through commencing by too powerful numbers, and neglecting hygienic rules, that the necessity is created for changing soon and often."

After No. 72 spectacles have been worn for night-reading for one or two years, need is felt for a stronger pair, and No. 60 may be substituted. Now, vision of small objects begins to be a little indistinct in the daytime, and the former night-glasses will be needed for day vision; with them small letters are distinctly and sharply seen. After about a year, No. 48 will be needed by artificial light, and then No. 60 will answer for day vision. As the degree of presbyopia increases these must be changed to No. 36 for night, and No. 48 will answer in good daylight. The change must not be made until an actual need is felt for doing so. Since the almost universal use of gas and petroleum-lights, the necessity for strong night-glasses is much less than in times past, when tallow, or even sperm candles were the chief sources of artificial illumination. All presbyopic persons who desire to keep their eyes in the most perfect state of preservation possible consistent with the inevitable senile changes, should have two pairs of spectacles — a stronger pair for night and a weaker pair for day use, and when a stronger pair is demanded for artificial light, the former night-glass may be substituted for daylight. Donders, who is the highest authority on this subject, says: " In general, it should be observed, that it is desirable to ascend but slowly with the numbers, to use the first spectacles in the beginning, only in the evening, and to keep these for day spectacles, so soon as stronger glasses are required for the evening, and thus every time that the stronger glasses are required, to continue using the former evening spectacles as day spectacles; finally, that, while

stronger glasses are necessary for reading, the weaker are often sufficient for writing, and are to be preferred, since the person wearing them, being enabled to see at a greater distance, can avoid the bent position, which is so injurious to the eyes."

It has often been attempted to adapt convex glasses to the eyes according to the age of the presbyope, but the individual differences in the state of refraction and accommodation at specified periods of life, are too great for such a rule to have any but an approximate value; hence, the method is empirical, and cannot be relied upon. If, however, persons have originally emmetropic eyes, with good general health, and no symptoms of premature old age, the following table, prepared by Donders, will in most cases be found to approximate the results obtained by actual scientific tests in each individual case. He commences at forty-eight years of age. We have added the first line, thus beginning at forty-five, for which glasses of $\frac{1}{72}$ will generally be found desirable.

Age.	In original Emmetropia.
45	$\frac{1}{72}$
48	$\frac{1}{60}$
50	$\frac{1}{40}$
55	$\frac{1}{28}$
58	$\frac{1}{20}$
60	$\frac{1}{18}$
62	$\frac{1}{12}$
65	$\frac{1}{10}$
70	$\frac{1}{7.5}$
75	$\frac{1}{6.5}$
78	$\frac{1}{5.5}$
80	$\frac{1}{4.5}$

If much stronger glasses than the above are necessary for the specified age, hypermetropia must be suspected; indeed, it is well in all cases of presbyopia that apply for the adjustment of glasses to test the eye for hypermetropia; it occupies only a minute or two of time, and we have the satisfaction of knowing the natural refractive state of the dioptric media. The patient is directed to look at No. XX, Snellen's test-types, hanging on the wall, at 20′ distant. If he sees the letters distinctly, then place $\frac{1}{72}$, $\frac{1}{60}$, $\frac{1}{48}$, $\frac{1}{36}$, or those still stronger, successively before the eyes; if he reads the letters equally well with as without them, he has hypermetropia, and the strongest glass with which he sees the letters distinctly indicates its manifest grade; this must be first neutralized; probably no other glasses may be needed for reading, but if he cannot easily

do so for a length of time at 8″, additional strength should be given the glasses to neutralize his presbyopia. If he be past fifty-five or sixty, and still reads fine print without glasses, or with $\frac{1}{48}$ or $\frac{1}{36}$, he has a low grade of myopia, and he cannot make out No. XX at 20′. Hence, if there be much variation from the Nos. of spectacles required for the ages specified in the table, there is ametropia. After the sixty-fifth or seventieth year we always expect a high grade of acquired hypermetropia in the originally emmetropic eyes, and then convex glasses are required for distant vision. In such cases the glasses *à double foyer*, a description of which is given on page 99, will be found very convenient. By simply elevating the eyes, the spectacles are adjusted for distant vision; turning the eyes downwards, they see through the glasses necessary for near vision. After an exhausting illness, young persons — particularly females — have a difficulty in keeping up for a length of time the adjustment of the eyes necessary for reading or doing fine work. In such cases the ciliary muscles, partaking of the general muscular debility, are unable to meet the demands made on them, and glasses $\frac{1}{72}$ will be found of temporary benefit.

There is a very prevalent opinion that constant use of the eyes in looking at small objects is injurious to them. "Those who are occupied almost the whole day in reading, writing, or other close work, usually accompany their demand for spectacles, with the observation that their eyes have suffered much, but that they have also exacted a great deal from them. I hasten to set such people right. Comparative observation has shown me that much close work does not essentially injure the eyes, at least those that are emmetropic, and that the range of accommodation diminishes scarcely, if at all, more rapidly under such circumstances, than it does in agriculturists, sailors, and others who for the most part look to distant objects." (*Donders.*) In the adaptation of spectacles to presbyopic eyes, the rules given under the head of spectacles should be strictly followed, particularly for the

stronger numbers; and, as in presbyopia glasses are required for near vision when there is a convergence of the visual axes, the mutual distance of the glasses should be less than those worn for distant vision.

In all theoretical calculations, the eye is considered simply as a dioptrical apparatus; to render these results practical, the associations existing between the ciliary and internal recti muscles must be taken into consideration. Glasses which would, theoretically, neutralize the errors of refraction, are usually too strong; "they compel the muscle of accommodation to a relaxation greater than corresponds to the developed circumstances of association."

A person in making trials for the selection of proper spectacles, without the assistance of the ophthalmic surgeon, should always begin with those which are a little too weak, and increase the numbers until he finds a pair that makes the letters at 10″, or 12″, look clear, distinct, sharply defined, and of the natural size — as near as possible as they looked before his eyes were presbyopic. If he makes trial at first of those that magnify too much, it interferes with his judgment; the objects look unnaturally large, bright, and distinct; when the really suitable glasses are found, he compares the impression they produce with those of the stronger ones, and is dissatisfied with them.

Empirics often take advantage of this, and select strong glasses for their patrons, who, finding that objects appear unnaturally clear and bright, imagine that it is owing to some peculiar quality in the material, or to the manner in which the lenses are made, and are ready to testify to the wonderful skill of the maker or vender. After using them, however, they find the eyes become painful, sensitive to light, inflamed, and the glasses have to be laid aside.

Many are prejudiced against glasses, and decline to wear them when their use is imperatively demanded. This is wrong; in attempting to look at small objects, they strain the muscles of accommodation by requiring them to act beyond their strength.

To preserve the sight unimpaired the longest possible time, it is requisite, as soon as it begins to fail, to select the weakest glasses that will make near vision easy; and as the failure at first is barely perceptible, very slight assistance is needed, and spectacles, No. 72, is all that is required. On first adjusting the eye for reading, should the print seem a little indistinct if it be carried off at arm's length and then brought near the eye, and this repeated three or four times, then at the normal distance the print can be easily read without fatigue. This action accounts for the temporary increase in the power of the eye to adjust itself for the near point, sometimes seen after the use of the so-called "eye-cups" and "sight-restorers," so extensively advertised by empirics, the action of which is to lessen the transverse diameter of the eyeball, and thus by pressure on the equator of the lens, forcibly to loosen the particles of the latter, which have been rendered too firm by senile changes. The lens is thus temporarily made more supple and yielding, so that it opposes less resistance to the action of the ciliary muscle.

HYPERMETROPIA.

The error of refraction now known by the name of hypermetropia,—previously mentioned by Ware and Stellwag,—was first described, and the knowledge reduced to scientific accuracy, by Donders, in 1848, and was one of the grand results of that careful and systematic investigation which has characterized the labors of many of the great minds of the age. Some of the previously obscure affections of the eyes, regarded as having their origin in the nervous structures, are now known to be caused by this error of refraction, or, to speak more correctly, by an abnormal form of the globe, in which it is shortened in its antero-posterior diameter. It must be borne in mind that in emmetropia, the eye, when the accommodation is absolutely at rest, is adjusted for parallel rays, so that sharply-defined images of distant objects are formed on the layer of rods and cones. The entire accommodative power is then free for the adjustment of the dioptric media for divergent rays emanating from near objects. In hypermetropia, on the contrary, the eye, at rest, is adjusted for rays converging to a point situated from a few inches to a few feet behind the retina. All rays of light are naturally either parallel or divergent, hence, the hypermetropic structure of the eye is adapted to a condition which does not exist in nature. In emmetropia the far point of distinct vision (r), is infinitely remote; in hypermetropia r is removed from an infinite to a negative distance, hence, in the latter formation of the eye, when it is at rest, there is no distinct vision, because the retinal images are formed by rays of light before they are united in a focus; each point of the image is surrounded by diffusion circles, and those from different points overlap each other. Any one having a convex lens, of, for example, two or three inches focal length, can easily see the effects on images of objects, when the screen on which they are formed

is nearer than the focal distance of the lens. If light be permitted to enter a room by a single window and fall on the lens, and a sheet of white paper be held in the focus of the former, sharply defined miniature images of distant objects, as trees, houses, etc., will be formed on the paper; every leaf and branch of a tree, or the windows and other parts of a house, will be sharply depicted. These are exact representations of images formed on the sensitive elements of the retina in emmetropic eyes at rest. If, now, the paper be gradually moved nearer to the lens, the images grow less and less distinct. The outlines of objects may still be made out, but all of the fine details are wanting; if the screen be brought still nearer, even the outlines of large objects disappear. The latter parts of the experiment show the condition of retinal images in hypermetropic eyes. If a lens of three inches focal length be employed, and the paper be held two inches from it, the images of objects are very indistinctly defined. If, now, a convex lens of $\frac{1}{6}$ be placed before the former, an almost magical effect is produced, the images instantly become perfectly defined in all of their minute shades of detail. Any one, after witnessing the above-mentioned results, can readily appreciate the effect of convex glasses placed before hypermetropic eyes; they are at once rendered emmetropic, and sharply defined images are formed in the retina. If the student with emmetropic eyes desires to practically experience the difficulties under which the hypermetrope constantly labors, he has only to render his own eyes hypermetropic, by placing before them concave glasses; if he begins with weak numbers, and successively changes them for those of higher powers, he will find that at first he can neutralize the effects of the negative glasses, by tension of the accommodation, but this becomes more and more difficult to accomplish, until finally, the maximum tension of the ciliary muscles is required to distinctly see distant objects; the entire power of accommodation is now exhausted, and if concave glasses of increased strength be used, he will no longer have distinct vision;

he has now absolute hypermetropia; convex lenses placed before the concave ones, of sufficient refractive power to bring the focus of parallel rays from remote objects within the range of accommodation, again restore distinct vision.

Hypermetropia (H.) is divided into *acquired* and *original*. In the acquired form, the eye is originally emmetropic, but owing to senile changes causing a diminution in the refractive state of the dioptric media, the focus of parallel rays falls behind the retina, and it continues to recede with the advance of age. This condition has been described on page 172. Original H. is either congenital or developed at a very early age, by the arrest of development of the globe in its antero-posterior diameter. Original H. is divided into *manifest* (Hm.) and *latent* (Hl.). The hypermetropic eye, in order to distinctly see remote objects, must be rendered emmetropic, so that parallel rays may be united in a focus in the retina. This is effected, when the grade is not too high, by means of the accommodation, so that while in E. the eye in distant vision remains passive, in H. it is always active; a part of $\frac{1}{A}$, being used to render the eye emmetropic, there is a corresponding amount of deficiency in the power of adjustment for near vision; for example, suppose in the hypermetropic eye $\frac{1}{A}=\frac{1}{4}$ and the degree of H. equals $\frac{1}{8}$, one-half of the former quantity; or $\frac{1}{8}$ is required to adjust the dioptric media for parallel rays; then $\frac{1}{4}-\frac{1}{8}=\frac{1}{8}=$ the available power of accommodation for divergent rays emanating from near objects, and *p.*, which, in the emmetropic eye, would be 4″ distant, is removed to 8″; but, as this state of adjustment requires the maximum tension of accommodation, which cannot be long maintained without producing nervous exhaustion of the ciliary muscles from over-straining, the near point very soon recedes still farther from the eye; if the objects looked at be small letters, although at first they are sharply seen, their borders soon widen out, grow indistinct, and the print has to be removed farther and farther from the eyes, until

finally the visual angle under which the letters are seen becomes so small that they cannot be defined. It would be theoretically correct to place before hypermetropic eyes, convex glasses which completely neutralize the errors of refraction, by giving parallel rays the degree of convergence for which the refractive media are adapted, and thus obviate the necessity for calling into action any part of the accommodation for vision of remote objects, so as to leave the entire $\frac{1}{A}$ free for the necessary adjustment of the eyes for divergent rays emanating from small objects when held near the eye. Practically, this is not found to answer — at least not until after long continued practice. The hypermetrope has always been accustomed to associate with vision, muscular action, and the habit thus acquired he is unable to voluntarily overcome, even when the errors of refraction are completely neutralized; hence, the strongest convex glasses, with which he sees equally as well as without, do not represent the total H.; a part, equal to the degree of involuntary contraction of the ciliary muscles, remains suppressed or latent; hence, to ascertain the total hypermetropia (Ht.), it is necessary to add the latent part to the manifest; thus, Hm. + Hl. = Ht. To illustrate: A patient with hypermetropic eyes is requested to read the letters No. XX Snellen's test-types at 20′; he does so easily; he reads them equally as well with glasses of $\frac{1}{20}$ placed before his eyes, but those of $\frac{1}{18}$ render the letters indistinct. His Hm. $= \frac{1}{20}$. If a strong solution of atropia — six or eight grains to the ounce of distilled water—be dropped into the eyes two or three times, at intervals of ten minutes, his accommodation soon becomes completely paralyzed; then, if the glasses of $\frac{1}{20}$, which equals his Hm., be again placed before his eyes, he is unable to read No. XX, and to do so, additional lenses of $\frac{1}{20}$ are required; hence, the suppressed part of his H. $= \frac{1}{20}$; and $\frac{1}{20} + \frac{1}{20} = \frac{1}{10}$ = Ht. The Hm. is equal to the amount of relaxation of which the ciliary muscles are capable when using the strongest convex glasses, through which distant vision is equally good with as without them, and the

focal length of the glasses measures its degree. It is often the case that a tolerably high degree of H. exists in the eyes of children and young persons, and yet it is entirely suppressed, and can only be detected by paralyzing the accommodation; then, Hm. = o and Hl. = Ht. Usually, at the age of eighteen or twenty years, Hm. appears, and increases with advancing years, while the Hl. diminishes, until finally it entirely disappears and gives place to Hm.

Donders divides Hm. into *facultative*, *relative*, and *absolute*. The former term applies to those cases of H. in which objects infinitely remote, can be distinctly seen both with and without convex glasses, or with the assistance of the accommodation. When the natural refractive state of the dioptric media, aided by the entire accommodative power, fails to bring parallel rays to a focus in the retina, distant vision can again be made positive by convergence of the visual axes. Relative H. represents the additional refractive power gained by convergence. Relative succeeds facultative H., but binocular must give place to monocular vision, which alone can be acute, because the visual lines of both eyes cannot be directed to the same point. When the accommodation, aided by the strongest possible convergence of the visual lines, is inadequate to bring parallel rays to a focus in the retina, the H. becomes absolute; there is no longer distinct vision without the aid of positive glasses to render rays of light convergent before they enter the eye.

Determination of H. and its Degree by means of the Ophthalmoscope.—It has been stated that the hypermetropic eye *at rest* is adjusted for convergent rays; hence, when its interior is strongly illuminated, rays thrown back from its fundus do not all return to the source of illumination; the rays emerge divergently from the surface of the cornea. If the H. be of high degree, and the eye of the observer, placed beside, or at some distance from, the edge of the mirror, sees the red reflex from the fundus of the observed eye, and is able to distinguish some of the retinal vessels, largely magnified, the

ment is often hereditary, and many members of the same family are similarly affected. Indeed, this is so frequently the case, that in examining a hypermetropic patient, many ophthalmic surgeons invariably ask him if other members of his family are not similarly affected, and if one or both of his parents did not begin to wear convex glasses at an unusually early age; the answer is generally in the affirmative. The optic nerve is smaller, contains fewer nerve fibres, and the retinal expansion is less than in the emmetropic eye.

The cornea and the iris are smaller, and the depth of the anterior chamber less, but the radius of curvature of the cornea is not lengthened, and in high degrees of H. it is sometimes shorter than it is in the emmetropic eye. High grades of H. are often expressed in the form of the face, and the peculiarity depends on the shallowness of the orbits. "The margins of the sockets are flatter, less curved, the whole face is flattened, with but little relief; there is little rounding in the cheeks, because the anterior surface of the face quickly passes into the lateral flatness. Often, too, the nose is but slightly prominent, and the upper part of its dorsum is so little marked that it can scarely give support to ordinary spectacles." (*Donders.*) It sometimes happens, that in the same person, E. exists in one eye, and H. in the other; in such cases, there is often a marked difference in the form of the bones of the two sides of the face. We recently saw a case of this kind. A young lady presented herself for treatment of stricture of the nasal duct. On looking at her face, a want of symmetry was noticed between the two sides, and in the size of the eyeballs. The right side presented the typical hypermetropic structure, both of the eye and of the face. An examination showed the left eye to be emmetropic, and the right hypermetropic of a degree $= \frac{1}{18}$.

The greatest deviation of the hypermetropic from the emmetropic structure, is in the length of the visual axes. It may be assumed that in the former condition the distance between the fovea centralis and the posterior scleral pole, is lessened

to a degree proportional to the diminished size of the eyeball, — in reality it is greater,— but, owing to the posterior flattening of the globe, these two points are relatively brought much nearer to the optical centre of the eye. This formation brings the posterior starting-points of the ocular and visual axes nearer to their point of crossing; hence, these lines enclose a larger angle. In the emmetropic eye, the angle *a* — this letter is used to represent the angle enclosed between the visual line and the ocular, or long axis of the cornea — is from 3° to 6°. In the hypermetropic eye, the angle *a* may vary in size from 6° to 11°.3. In six cases examined by Donders, the maximum size of angle *a* was 9°, the minimum 6°; the average 7°.55; the average length of the visual axes was 15.32 *mm*. The relative position of the visual line to the ocular axis, in H. is shown in Fig. 61 above; *l'* represents the situation of the fovea centralis; *g*, the posterior pole, or the point where the ocular axis passes through the retina; *n*, the optic nerve entrance; *k*, the nodal point; *a g*, the prolonged ocular axis; *l l'*, the visual line. It will be seen that the visual line cuts the cornea at a greater distance from its zenith than in the emmetropic eye, as it is represented in Fig. 62; this distance necessarily varies with the size of angle *a*. It should be mentioned that the position of the centre of rotation of the hypermetropic structure is relatively moved farther back on the shortened ocular axis; this change, together with the oval form of the smaller eyeball, from the flattening of its posterior part, renders a less amount of muscular contraction necessary to produce equal excursions of the eye from the primary position than in the emmetropic eye, and the movements are less regular. The latter effect is not particularly noticeable in slight changes of the eye from the primary position; but if, for example, there be H. of $\frac{1}{4}$ or $\frac{1}{5}$, and we watch the eye while it is turning inwards, the movement is at first slow and regular, until after the ocular axis has attained a certain position, when suddenly the eye seems,

as it were, to tilt on its side, and the cornea is almost hidden from view within the inner canthus; the plane of the equator is directed forwards, so that the length of the ocular axis may be measured almost with the same facility as if the eye were removed from the orbit. Owing to the visual axis cutting the cornea farther within its zenith, a less degree of convergence of the long corneal axes is necessary for binocular near vision. We become accustomed to the positions which the corneal apices of the normal eyes assume, when we observe persons viewing objects situated at different distances.

In high grades of H., to an observer, the eyes seem to be fixed on an object farther off than the one they are actually looking at, and when the visual lines are parallel, the ocular axes may enclose an angle of from twenty to twenty-two degrees; thus giving rise to what is apparently a divergent squint, although in reality the visual lines are parallel. This condition will be easily understood by referring to the figure, and drawing or imagining the representation of a horizontal section of the opposite eye to be placed above the one shown in Fig. 61; then, if the representations be so changed in position that the visual lines $l\ l'$ become parallel, the ocular axes will, if prolonged backwards, meet at a certain distance behind the eyes, and they will enclose an angle twice the size of angle a.

Vision of Hypermetropes.

In youth, vision, in the lower grades of hypermetropia, usually = 1, and H. is often entirely latent, so that the error of refraction can only be detected by means of the ophthalmoscope or by paralyzing the accommodation; but in the higher grades, as, for example, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$, sight is usually defective, even when the H is completely neutralized by convex glasses. This deficiency is probably owing to the diminished distance of the retina from the nodal points, causing the magnitude of the retinal images of objects to be proportionately smaller than in emmetropic eyes; con-

sequently, they impress fewer of the perceptive nervous elements. This diminution in the sharpness of vision continues, to a greater or less extent, even when the magnitude of the images is increased by moving the glasses farther from the eyes, thus showing that the rods and cones corresponding to a smaller optic nerve are fewer and less compact, particularly in the region of the yellow spot, than in normal eyes; it is also probably owing to this reason, that persons having high grades of H. see badly at night, or in dimly-lighted apartments; persons strongly hypermetropic sometimes partially close their lids, and bring small objects well illuminated within two or three inches of the eye, at which distance they for a time see distinctly. The explanation of this phenomenon is, that the size of the visual angle is inversely proportional to the distance of the object looked at, and, as the latter is brought very near to the eye, the size of the retinal images increases to a much greater extent than the circles of diffusion. The strong illumination necessary diminishes the size of the pupil, which, aided by the partial closing of the lids, shuts out the circumferential rays, the aberration of which adds largely to the diffusive circles, while they learn to a great extent to suppress the impressions of any ununited rays which may pass through the central portions of the dioptric media — by practice, these hypermetropes occasionally learn to do fine work or read small print without the aid of glasses, and are often thought to be very near-sighted. They can, however, see with positive glasses infinitely remote objects which the myope is unable to do. The emmetropic eye, even when presbyopic, can, with a little practice, read fine print (No. 1, Jaegar) held one or two inches distant; to do this it requires a strong light, not only to illuminate the print, but to contract the pupil to its minimum size, when, by partially closing the lids, so as to form a stenopæic slit, the print becomes very black, clear, sharply defined, and magnified two or three diameters. The same result is accomplished

by looking through a minute hole in a blackened card, or a thin metal plate; and the principle involved is probably the same as in the formation of images in a darkened room by allowing light from objects to fall on a screen after passing through a pin-hole in a piece of tin-foil. Practically, we may say a single ray from each point of the object passes through the hole and falls on the screen, forming the image. So in the eye, the image is formed by the primary and secondary axis rays alone which enter the eye — one from each point of the object.

Asthenopia.

Asthenopia may be defined to be the want of sufficient potential muscular energy to maintain, for a length of time, the adjustment of the dioptric apparatus or the visual axes, required for near vision, and the nervous and vascular excitement resulting from the effort. Asthenopia is divided into *muscular* and *accommodative;* the former term is applied to those cases in which there is a deficiency of nervous energy of one or both of the lateral recti muscles necessary to keep up the proper degree of convergence, either relative or associative, of the visual axes for near vision. This insufficiency, although it sometimes occurs in H., is chiefly met with in the higher grades of myopia, in which small objects, to be distinctly seen, must be brought very near the eyes; hence, a description of the symptoms and treatment of this form of the disease comes more appropriately under the head of myopia, where it will be again referred to.

Accommodative asthenopia is one of the chief attending symptoms of H., in which condition of the eye a part of the accommodation is diverted from its legitimate purposes, in order to unite parallel rays in a focus on the perceptive elements of the retina, leaving a corresponding deficiency in the power of adjustment for divergent rays, so that in the exercise of near vision, an extraordinary degree of tension of the muscles of accommodation is required The result is, that

the potential muscular energy is soon exhausted, and the tension of the fibres gives way, with supervening symptoms of muscular fatigue.

This defect is not usually manifested at a very early period of life, because young children seldom exercise their eyes for any considerable length of time in looking at small objects; but usually between the ages of ten and twenty years, when the eyes are exercised for a length of time in reading, writing, or doing fine work, symptoms of accommodative asthenopia appear, and cause much suffering and annoyance, and frequently give rise to painful forebodings of future blindness.

In accommodative asthenopia there is perfect near vision for a time, but the required tension of accommodation for the exercise of the eyes in seeing small objects cannot be kept up, and, notwithstanding an increased effort is made to overcome the deficiency of potential nervous energy, the muscles of accommodation give way from exhaustion; this is followed by a sensation of fatigue within the eyes, supra-orbital pain, with hyperæmia and excessive irritability. The retinal images become blurred, and the straining of the accommodation to form distinct images, renders the eye sensitive to strong light, particularly if it be artificial, causing a painful dazzling and a sensation of smarting and roughness, as if there were sand beneath the lids, followed by slight swelling of the latter, with increased mucous discharge, which, drying, frequently glues together the edges of the lids during sleep. After a period of rest, during which time the sufferer closes the lids and rubs or presses the eyes with the fingers, these symptoms disappear, but they return with increased violence after prolonged straining of the ciliary muscles for continued near vision, particularly if the illumination be bad, until, finally, the required adjustment of the dioptric apparatus can be maintained only for a few minutes at a time.

The pain and irritation become so great that reading, writing, or doing fine work has to be abandoned, and unless

artificial assistance be given, some occupation must be sought which requires but little exercise of the eyes for sharp vision of small objects. In muscular asthenopia, letters run into each other, or are seen double. In accommodative asthenopia, the borders of the letters widen out and the angles lose their sharpness, so that their forms cannot be distinguished. In the former case the visual axes of the two eyes cease to be directed to the same point; in the latter, the accommodation alone is at fault. There is an *actual* and a *potential* muscular energy recognized; the former acts to cause a muscle to contract, the latter to maintain the state of contraction. In accommodative asthenopia, it is seen that there is sufficient *actual* energy of the ciliary muscle to adjust the lens for the normal near point, but a lack of potential *energy* to maintain that adjustment for a length of time. In the emmetropic eye no muscular effort is required to see at a distance; consequently, the entire power of accommodation is free to be used as may be required for near vision. On the contrary, in H. there is no distinct vision even at a distance, without a partial contraction of the ciliary muscle; consequently, the accommodation begins with a deficiency, or, in familiar parlance, it has "extra weight to carry," and, as a matter of course, gives out sooner when great exertions of it are demanded. This condition may be illustrated by the deltoid muscle which raises the arm. If one's occupation requires that the arm shall be frequently elevated, and kept for some time in that position, the deltoid muscle may be fully equal to the task imposed on it. Now, if a ring of iron weighing ten pounds be immovably attached to the wrist, then every time that the arm is elevated, a portion of the muscular energy is exhausted in lifting the iron ring; hence, there would be that amount of deficiency in the strength of the muscle, and if required to perform the same amount of labor, that it was able to accomplish before the weight was attached to the wrist, the muscular energy would sooner be exhausted. To carry out the simile, the weight of the iron

ring corresponds to the grade of the H. If the weight be increased, or the grade of the H. be higher, the muscle gives out that much sooner. On the contrary, with diminished weight, or a lesser degree of H., labor may be longer performed without fatigue or asthenopic symptoms supervening. Hence it is evident that the length of time that the accommodation can remain adjusted for a near point is dependent upon the grade of the H., or the amount of "extra weight" the ciliary muscle has to carry. In childhood, when the lens is quite soft and yielding, and the muscle strong and well developed, a high grade of H. may exist and pass unnoticed; but as the crystalline lens becomes more firm, and the exercises at school demand a greater use of potential muscular energy, symptoms of asthenopia usually appear, and soon become very annoying. In the slighter degrees, youth may pass without serious trouble, but presbyopia — a recession of the near point beyond eight inches — begins at an unusually early age. Accommodative asthenopia, not dependent on H., is often met with after exhausting illness, and in females of lax muscular fibre, in whom any slight exertion is attended with fatigue. The ciliary muscle, partaking of the general feebleness of the system, is deficient in potential energy, and soon becomes exhausted when called into action. With the improvement in the general health the asthenopic symptoms pass away.

Treatment of Hypermetropia.

In absolute H., objects with the naked eyes are indistinctly seen at all distances — vision is entirely negative. The whole power of accommodation fails to unite parallel rays in a focus in the retina; consequently, these must be rendered convergent before they enter the eye, by means of convex glasses. Usually two pairs of spectacles are required; one pair should be selected which makes remote objects distinctly seen, and another that enables fine print to be easily read at

about twelve inches distance. When the range of accommodation is greatly diminished, points situated at an intermediate distance may be rendered more distinct by moving the glasses farther from the eyes, as circumstances may require. When very strong convex glasses are used, a slight alteration in their distance from the eyes is equivalent to a change for those of a greater or lesser power, as may be needed to make the object more distinctly seen, thus obviating the necessity of glasses of intermediate foci. In spectacles of high power, care should be exercised to have the glasses properly adjusted or centred. As these are usually required for near vision, where there is a strong convergence of the visual axes, the centres of the lenses should be so near to each other that the visual lines may pass through or near their axes. If this be neglected, and the rays of light pass too near the edges of the lenses, they are refracted as by prisms with curved surfaces, causing a disturbance of the normal conditions of association that should exist between accommodation and convergence, which is often attended by painful nervous and vascular excitement. In facultative H., where vision is acute both for near and remote objects, and the accommodation can be maintained in a state of tension without fatigue as long as may be desired, no treatment is necessary; but in such cases the recession of the near point beyond eight or ten inches, usually takes place by the age of twenty-five or thirty years, rendering convex glasses necessary for reading, writing, etc., or doing fine work.

Accommodative asthenopia owes its origin, as already shown, to the faulty formation of the eye, whereby an unusual amount of muscular power is required to adjust the dioptric apparatus for near vision. Now, a convex lens placed before the eye is equivalent to the expenditure of a certain amount of muscular force, because, by the use of the lens, the demand for the excessive contraction of the ciliary muscle is obviated. In other words, the artificial lens relieves

the overburdened muscle of the "extra weight" it has to carry. The question now arises, What should be the power of the required lens in each individual case? It has been shown that ordinarily there is a part of the H. that is manifest, and a part that is latent. Theoretically, it would seem proper, as previously stated, at once to neutralize the total H., but in practice, glasses that accomplish this are found to be too strong. In facultative H., there is an excessive active contraction of the ciliary muscle, which represents the latent or suppressed portion. After glasses which neutralize the total H. are placed before the eyes, the muscle does not relax sufficiently to make the suppressed portion manifest; the active contraction still continues; hence, to that extent there is a double power acting, which may increase the very symptoms it is sought to relieve. The rule, then, is, not to attempt to completely neutralize the total H. at once. When the patient can be kept for some time under observation, it is preferable to adapt glasses which just neutralize the Hm., and direct them to be worn only for near vision of small objects, resting the eyes every twenty or thirty minutes by looking for a short time at a distance. After a few weeks' use in this manner an additional portion of the Hl. becomes manifest, when the glasses may be changed for those a little stronger. Finally, the suppressed portion becomes entirely or almost entirely manifest; then the glasses corresponding to the grade of the total H., are the proper ones to select, and no further changes become necessary until after the inevitable senile changes take place. Should the patient be so situated that he can be seen but once, and it becomes necessary to choose permanent glasses on that occasion, Donders advises that those should be selected which neutralize the Hm., and about one-fourth of the Hl., which, although too strong at first, will, in the course of a few weeks, become suited to the eyes. Should they be constantly worn for distant vision? The patient sees remote objects equally as well without as with spectacles; hence, there is no real necessity for their constant use; the effect of

which would be to cause the eyes gradually to lose the power of seeing remote objects distinctly without them; this is often a great inconvenience, as the glasses, when needed, may not always be at hand. Again, when spectacles are worn to see at a distance, the scope and symmetry of the field of vision, from the movements of the eye by the external ocular muscles, are greatly diminished, because the glasses cannot turn with the eyes; hence, when looking far outwards or inwards, upwards or downwards, the visual lines pass beyond or near the edges of the glasses, and vision then becomes indistinct; consequently, additional movements of the head are required in order to bring the visual lines to pass through the central portions of the lenses. It occasionally happens that in long-continued sight-seeing, as in viewing objects on the stage of a theatre, or at an exposition, gallery of paintings, etc., symptoms of fatigue appear; recourse should then be had to the glasses. Indeed, there can be no objection to their being habitually worn on such special occasions, in order to lessen the increased amount of muscular energy demanded. It is sometimes the case that when convex glasses are at first placed before the eyes, objects appear to be magnified and at a greater distance than they really are; in walking, the pavement seems to recede, so that the patient feels as though he was stepping in a hole or depression. Judgment of distances is an acquired faculty. We learn by experience that for every specified distance there is a certain degree of convergence of the visual axes to which corresponds a definite amount of tension of accommodation. From these conditions of association between convergence and accommodation, we derive our ideas of the distance of objects. When the hypermetropic eyes are first made to look through positive glasses, the accommodation relaxes; the tension is then less than the eyes have been accustomed to for certain degrees of convergence; the patient involuntarily associates the relaxation of the ciliary muscle with an increased distance and size of the object. With practice, he soon becomes accustomed to

the modified conditions of association, and learns to correct his judgment accordingly. "It is a great satisfaction to be able to say that asthenopia need now no longer be an inconvenience to any one. In this we have an example, by what trifling means science sometimes obtains a triumph, blessing thousands in its results. The discovery of the simple fact that asthenopia is dependent on the hypermetropic structure of the eye, pointed out the way in which it was to be obviated." (*Donders.*)

Another form of asthenopia has its origin in the disturbance of the normal relative associations which should exist between accommodation and convergence With a fixed degree of convergence, the positive should bear a certain proportion to the negative part of relative accommodation. If either be in excess there will be a strain on the muscles of accommodation or convergence, as the case may be, in order to maintain the necessary adjustment. This condition will be easily understood by referring to the figures on page 85.

The treatment consists, either in the adjustment of spherical glasses, or in the use of weak prisms, to slightly change the degree of convergence.

NOTE. — The great frequency of accommodative asthenopia having its origin in the hypermetropic structure of the eye, renders it important that its nature and treatment should be thoroughly understood by general practitioners of medicine, and I add this note with the view of impressing upon them and the educated public the important bearing of this subject upon a condition of the eyes, affecting so many children and young persons, and will elucidate its nature and symptoms still further, by the clinical report of several cases.

"He who knows by experience how commonly H. occurs, how necessary a knowledge of it is to the correct diagnosis of the various defects of the eye, and how deeply it affects the whole treatment of the oculist, will come to the sad conviction that an incredible number of patients have been tormented with all sorts of remedies, and have been given over to painful anxiety, who would have found immediate relief and deliverance in suitable spectacles." (*Donders.*) Adults who have had hypermetropia from childhood, and who now understand the nature of it, frequently

speak of the sufferings they endured while attending school. Owing to an inability to study for any considerable length of time, they were frequently unable to accomplish the tasks assigned them, and for this cause, were too often accused of stupidity; their complaints of headache and fatigue of the eyes, were treated as an excuse for idleness, and if, perchance, they put on their grandmother's spectacles, and found, to their delight, that they could read with ease, yet, if detected, they were reprimanded and threatened with punishment if again seen wearing them; and as they grew older and determined to experience the benefit to be derived from artificial assistance, they were constantly reminded of threatened loss of vision, and that the danger would be greatly increased by wearing glasses. Even as late as 1848, Mackenzie, in his then exhaustive treatise on "The Diseases of the Eye," advises such sufferers not to use glasses, but rather to give up literary for rural pursuits.

Many ambitious young men, with a fondness for study and high aspirations for professional distinction, have had their hopes nipped in the bud by increasing difficulties of continued near vision in reading, writing, etc., and although they found relief from positive glasses, have been advised by those in whom they confided, not to wear them, but rather to go to the country and seek some occupation which calls for but little exercise of accommodation. There is scarcely a teacher in any of our schools who has not one or more pupils who, after much study, particularly by artificial light, does not suffer from fatigue, with nervous and vascular irritation of the eyes, accompanied by headache, and whose annoying symptoms would vanish if permitted to wear properly adjusted convex glasses; but, owing to a want of knowledge on the part of their physician, they are doomed to a continuance of the sufferings and inconvenience of defective vision. The great frequency of such cases renders it important that not only members of the medical profession, but educated persons, and particularly teachers, who can easily comprehend the subject of hypermetropia, should be, to some extent, familiar with it, so that they may make due allowance for the complaints of their pupils, and, at the same time, by the proper diffusion of knowledge, overcome the prejudice so widely existing in the public mind against wearing convex glasses, even when their use is imperatively demanded to overcome some natural or acquired defects in the eyes.

Case I. A. B., aged sixteen years, comes in for advice; says he has weak eyes; they present no external appearance of disease; are small, prominent, and set widely apart; his pupils act freely to the stimulus of light; has a sister younger than himself who has a convergent squint; an older brother who suffers like himself, but to a less degree; his father commenced wearing glasses at the age of thirty — his general health is good; he attends school and is inclined to be studious, but

after reading or writing for a length of time, his eyes grow tired and the letters become indistinct; he moves the book farther from the eyes and sees better for a time, but soon the letters again appear blurred; he once more changes the position of the book, but to no purpose; the eyes grow more and more fatigued, accompanied by slight watering, with a sensation of smarting and supra-orbital pain, the letters grow pale, their borders and angles widen out, so that the characters appear as confused, dark, irregular spots on the paper; he can read no longer; he closes the lids, rubs or presses the eyes with his fingers for a few moments, then looks at distant objects, which he sees distinctly; after resting the eyes for a few minutes he again looks at his book and finds the letters black and sharply defined, but the eyes soon give out, and he goes through the same process of closing his lids and pressing the eyes; his headache increases, the conjunctiva becomes slightly injected, and if he continue his efforts to study, he becomes sick at the stomach. Thus he worries through the day; he attempts to study at night, but his eyes are sensitive to strong artificial light, which produces painful dazzling, with a feeling of roughness, as of sand beneath the lids; he awakes in the morning and finds them slightly glued together, but after bathing his face feels all right again — returns to school and has no trouble in studying for the first hour or two, but the asthenopic symptoms return, and he goes through the experience of the previous day. After resting Sunday he has less trouble with his eyes on Monday. He experiences no inconvenience whatever during vacation; has been for a length of time under the care of Dr. Blank, who told him that he had "an affection of the optic nerve;" has been kept on low diet,—taken mercury, strychnine, and other medicines; had been blistered and "eye-water" dropped in his eyes. He was requested to read No. XX Snellen's test-type hanging on the wall 20′ distant; he does so easily; he also reads it with $\frac{1}{24}$; $\frac{1}{20}$ slightly dims the letters; his Hm.$=\frac{1}{24}$; the ophthalmoscope shows Ht.$=\frac{1}{18}$; he is then requested to read No. 2 Jaeger, holding the book as near to the eyes as he can distinctly see the letters; he reads the first line at 6″, but says that the effort is painful; he moves the book at 10″ in reading the second line, and by the time he had finished the paragraph it is held at 12″ from the eye. With glasses of $\frac{1}{28}$ he reads the print at 8″ easily for a length of time, and at 10″ reads for an indefinite period without pain or any unpleasant sensations; glasses of $\frac{1}{28}$ are prescribed for him, — he answers, "Why, doctor, you don't want me to wear spectacles?" "Certainly," I replied; "or, at least, I wish you to try them." He then said, "I used to put on my grandmother's spectacles at night to get my lessons, and could study as well as anybody, but when I told Dr. Blank, he said I must not use them any more, for they would ruin my eyes and make me blind." Notwithstanding Dr. Blank's advice, he returns to

school, wears the prescribed spectacles, and no further complaints are heard from him.

CASE II. Mr. ——, twenty-six years of age, called in the summer of 1873 to consult me in regard to his eyes. He belonged to a family distinguished for talent, several members having risen to enviable positions in the councils of the State, at the bar, and in the pulpit. He had completed his collegiate course, and had intended to study law, but, owing to increasing asthenopic difficulties, and acting under the advice of those who were incompetent to give it, he abandoned his studies and went to the country, where he remained two years. I found that he had Hm. $= \frac{1}{28}$, and gave him glasses $\frac{1}{26}$. On his return to the city at the end of a year, he called to see me to express his gratitude for the great benefit he had received from wearing the glasses that I had prescribed for him. He stated that he had used his eyes freely in reading and writing without suffering any inconvenience whatever.

CASE III. Mrs ——, aged about forty-five years, called at my office with her husband, to consult me in regard to the condition of her eyes, which she said had given her trouble from childhood; they were small and showed no external signs of disease; she had great difficulty in reading or doing fine work, and distant vision was somewhat defective; she had been some time previously under treatment of a physician who regarded her case as one of amblyopia, and prescribed for her accordingly. He had assured her that unless she exercised great care, vision would eventually be lost; she also stated that she had for a long time hesitated before making up her mind to seek further advice, fearing that the unfavorable prognosis previously given, would be confirmed. I found that she had Ht. $= \frac{1}{12}$, all of which was manifest. Glasses of $\frac{1}{12}$ were given her, with which she saw well at a distance, and read medium-sized print (No. 4 Jaeger) at 12″. The nature of her affection was explained to her, and she was requested to dismiss her fears of future blindness, but her painful apprehensions had taken such deep root in her mind, that with a lingering doubt lest possibly my opinion in regard to the termination of her case might be too favorable, she afterwards, while in NewYork city, consulted an eminent ophthalmologist, who fully confirmed my diagnosis, prognosis, and treatment in every respect, and her unpleasant forebodings have since vanished.

CASE IV. In the fall of 1873, a little girl seven years of age, was brought to me. Her parents thought her very near-sighted, and feared that she would soon lose what vision she then had. Her eyes were small, and on looking far inwards, the cornea was almost hidden from view within the internal canthus; the sharp curve of the meridians as they passed over the equator of the globe were very marked, and the posterior portion of the sclerotica nearly flat, $V = \frac{20}{300}$. She made out letters

by holding the book two inches from the eye; had convergent squint, fixing only with the right eye; the retina of the left was anæsthetic from psychical exclusion. The ophthalmoscope showed Ht. $= \frac{1}{5}$, which was corrected by glasses of $\frac{1}{6}$ held an inch from the eyes; with them $V = \frac{20}{50}$. She now goes to school and holds her book at about 6″, in order to get the benefit of the increase in the size of the retinal image from a large visual angle.

CASE V. In November, 1874, I saw a boy nine years old, who was thought to be highly myopic. In spelling out his letters he held the book an inch and a half or two inches from his eyes, always seeking a very strong light, and could not recognize the features of persons across the room; he had convergent squint whenever he endeavored to sharply see distant objects. His eyes presented the strongly marked hypermetropic structure, being very small, and the posterior part of the sclerotica very flat; indeed, to make familiar comparison, they had the form of a turnip-radish. $V =$ less than $\frac{20}{100}$. It required a lens of $\frac{1}{5.25}$ to make the divergent rays from his eyes parallel. Spectacles of $\frac{1}{6}$ were given him; with these held three-quarters of an inch from his eyes $V = \frac{15}{30}$, and he read No. 4 Jaeger, at from 6″ to 8″. He now goes to school and has no difficulty in learning his lessons. In neither of the latter two cases can vision be made normally acute, owing to the smaller optic nerve and the corresponding diminished retinal expansion. Cases resembling the above are daily seen by the ophthalmic surgeon in large practice, and many of them have been under the charge of the general practitioner, who had subjected them to harsh treatment for what they called amblyopia.

Convergent Squint.

It has been shown by Donders, that a very large proportion — not less than three-fourths — of the cases of convergent strabismus, have their origin in hypermetropia, and that this condition could have been prevented by the timely use of convex glasses. It most usually appears at about the age of five years, when the child begins to fix objects sharply; sometimes it does not show itself until he attends school, and is required to read, write, etc., or do fine work. It has been stated that there is an increase in the power of accommodation from the convergence of the visual axes; the higher the degree the greater is the power gained. The visual lines can be made to cross each other at a point nearer than

14

that of binocular fixation, and an increase in the amount of accommodation be thus gained, but binocular must give way to monocular vision at the expense of double images, for when the visual line of one eye is directed to a point fixed, the image is formed at the yellow spot — the place of direct vision. The visual axis of the other eye is directed to another point of the object, or even to a different body; consequently, the corresponding image in the second eye is formed on its retina at a distance from its yellow spot; thus two similar impressions are made upon parts of the two retinas, which are not identical, and the object is seen double. As the fixing eye has the image of the object desired to be seen formed on the most sensitive part of the retina, the attention is specially directed to this, and a positive impression is produced, of which the brain takes sharp recognition. The corresponding image in the deviating eye, formed at a distance from the yellow spot, where the nerve is less sensitive, produces a more feeble impression, and as this image tends to confuse the distinct perception sought to be made by the fixing eye, there is an effort made by the perceptive elements to suppress its recognition. Herein lies the true explanation why facultative and relative H. lead to the development of convergent squint, and, as a consequence, to the formation of homonymous double images. (The reverse takes place in myopia; this is the most frequent cause of divergent strabismus.) The hypermetropic child, when he begins to look closely at near objects, finds that he cannot see them distinctly, or if at first seen sharply, a considerable effort is required in order to keep up the desired tension of accommodation; he soon finds that by squinting inwards, vision in one eye becomes sharper, and the effort required to accommodate is less. Hence, when he desires to see distinctly a near small object, he unconsciously fixes on it one eye, while the visual axes are converged so as to cross at a point nearer the eyes. As soon as he looks at a distance, both eyes immediately resume their normal posi-

tions, and they continue to act in harmony until again called upon to fix for a near point, when the squint returns; the child prefers sharp monocular to imperfect or strained binocular vision. The squint thus becomes periodical, recurring whenever great tension of accommodation is demanded, and disappearing as soon as the eyes are at rest, or turned on distant objects. After a while, the eyes are slow in resuming their natural positions and movements; the squint lasts for a considerable length of time after they are at rest, until finally, it becomes permanent, and there is no longer binocular vision. If the eyes are alternately exercised, the sight remains equally good in either eye; but generally one alone is used, while the other failing to take cognizance of its retinal images, its powers of perception are gradually diminished, until finally the faculty of vision is to a great extent lost. In the deviating, or unused eye, no organic change in the retina takes place, but from psychical exclusion the sensibility of the nerve becomes blunted. Should the fixing eye be lost, or through tenotomy or other means the eyes again act in harmony, the impaired sensibility of the retina is gradually restored by use, and this result is made more rapid by exercising it a few minutes each day with a strong convex lens.

The question naturally arises, why, if hypermetropia be so common an anomaly, do we not meet with more cases of convergent strabismus, as its secondary result? The question is easily answered. In absolute H., there can be nothing gained by excessive convergence, because, with the addition of the strongest tension of accommodation, vision still remains negative. In hypermetropic, as in normal eyes, there is a necessity felt for single vision, and the ocular muscles strive to accomplish this result, as illustrated by holding a prism before one of the eyes, when a strong effort is made to fuse the double images, by changing the direction of the eye, so that the deviated image from the rays bent by the prism may still be formed on the yellow spot, at points identical with those of the other eye. There is, then, a struggle

between two contending impulses; one, from an abhorrence of double images, to see singly with two eyes, although at a sacrifice of distinctness of vision; the other, to see acutely, which can only be accomplished with one eye at the expense of double images. In the former case the brain strives to form a clear impression from indistinct images; in the latter it endeavors to suppress the impression produced by the image formed at a distance from the yellow spot. In the struggle between these two contending impulses, in a majority of cases, the abhorrence of double images, and the natural desire for binocular vision, act so strongly, that the effort for acute monocular vision gives way, and the squint is thus prevented. It is probable that some hypermetropic persons pass through childhood without discovering that excessive convergence largely increases the power of accommodation. It was formerly thought that many cases of strabismus were caused by imitation. It is hardly probable that such would be the result from that cause, in emmetropic eyes, but in the effort to imitate the squint of others, the hypermetropic child may for the first time *discover* that the acuteness of vision may be decidedly increased by squinting, and when he wishes to see distinctly, take advantage of the discovery, and before he is aware of it, have permanent convergent strabismus. The reason why squint does not often appear after the age of twelve or fifteen years, is that the crystalline lens then becomes more firm and is less easily acted on; consequently, the amount of accommodation gained by strong convergence is much less, and the impulse for sharp monocular vision is proportionally diminished. It is hardly necessary to say that convergent squint, being the secondary result of H., may be prevented by the timely neutralizing the errors of refraction by suitable convex glasses. As a matter of course, there is great difficulty in making a child, five or six years of age, wear spectacles. It has not the judgment to appreciate the object for which they are prescribed, and is inclined to regard them as "playthings" given it for amusement; hence it

requires much firmness on the part of the parents to control the inclination of the child to remove the glasses, or to prevent their being broken. Many parents are not disposed to take on themselves all of this trouble, but prefer to allow the periodic squint to become permanent. When the latter condition has taken place, each eye should alternately be used, in order to prevent retinal anæsthesia, from psychical exclusion. If the child be inclined constantly to fix with the same eye, this should be covered with a bandage for an hour each day, and the child required to use the other for vision. This practice tends to prevent either retina from losing its normal sensibility, so that if at any time, by means of a successful tenotomy, the natural position and movements of the eyes should be restored, there would be a better prospect for the return of binocular vision. Again, in case the eye most used should be lost from accident or disease, the other would be in a better condition to supply its place. It is undoubtedly a matter of great importance to the child, that the periodic squint should be prevented from becoming permanent, for it is a doubtful question, whether, after the most successful surgical operation for the cure of the latter, perfect single vision with the two eyes — that is vision the same as if but a single "cyclopean" eye were placed centrally between the two — is ever perfectly restored. The falling experiment of Hering shows "that, in a great number of cases, which were operated on with the most favorable result, and in part of which not the slightest objective trace of deviation could be found, there was *not one* in which binocular vision appeared." (*Stellwag.*)

Aphakia.

Aphakia is the term given by Donders to represent that condition of the eye in which the crystalline lens is removed from the plane of the pupil. It may result from luxation and its removal to another position in the eye, or, after puncture or rupture of the anterior capsule, it may be

dissolved in the aqueous humor and removed by absorption. The most frequent cause of the absence of the lens is its extraction from the eye by operations for cataract. In aphakia two refracting surfaces are wanting, leaving a single dioptric system having its focus at a considerable distance behind the retina; hence, the eye is in a state of absolute H.; if, however, the eye, previous to the loss of its lens, had a grade of M. sufficiently high, it may in aphakia be emmetropic; this is a very exceptional result; so, if the eye were previously hypermetropic, the resulting degree of absolute H. will be proportionally greater. Accurate experiments, made under the most favorable circumstances, have conclusively proved that in the absence of the crystalline there remains not the slightest trace of accommodation; this fact establishes the correctness of the universally adopted theory, that the power which the eye possesses of seeing distinctly at different distances is due solely to changes in the form of the crystalline lens. The eye being left in a condition of absolute H., it becomes necessary to learn the degree, and this can be accomplished either by trial lenses, or by ophthalmoscopic optometry, with a view of neutralizing the error of refraction of parallel rays; but when this is accomplished, owing to the absence of accommodation, there is vision only of distant objects; for near vision stronger glasses must be used. Generally, for distant vision, glasses of $\frac{1}{3\frac{1}{2}}$ to $\frac{1}{4\frac{1}{2}}$, and for near vision $\frac{1}{2\frac{1}{2}}$ to $\frac{1}{2}$ answer the required purposes. Accommodation for intermediate points can be effected by changing the distance of the spectacles from the eyes. Even after the most successful operations for cataract, vision can rarely be made to = 1. Donders attributes this defective result to a turbidity in the plane of the pupil, from a deposit of slightly opaque matter on the posterior capsule, which can be seen by an observer with the aid of the ophthalmoscope or by oblique illumination.

MYOPIA — NEAR-SIGHTEDNESS.

Myopia, or near-sightedness, as already stated, is a condition exactly the reverse of hypermetropia; the eye is too long in the direction of its visual axis. Whilst in H., rays of light emanating from distant objects (parallel rays) fall on the retina before they are united, in M., parallel rays unite in a focus before they reach the retina; they overcross in the vitreous humor and fall on the sensitive nervous layer in circles of diffusion; consequently, there is no distinct image formed. This is shown in Fig. 63. Parallel rays

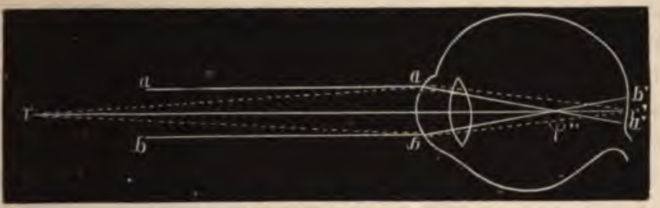


Figure 63.

from objects infinitely remote meet in front of the retina at φ''; the rays from each point, therefore, crossing at φ'', form on the retina circles of diffusion; hence, infinitely distant objects are indistinctly seen; for sharp vision they must be brought nearer the eye, as at *r*, so that the rays from each point of the object may enter the eye divergently; the focus is then thrown backwards, as in the figure; the dotted lines from *r* are divergent and meet in a focus on the retina, and there is a sharply defined image of the object; *r*, then, is the far point of distinct vision, and the measure of the distance of *r* from the eye (strictly from the anterior nodal point) represents the grade of the myopia. As near-sightedness depends on an abnormal increase of the distance of the retina from the optical centre of the eye, it follows, that the

greater the elongation of the eye posteriorly the nearer is the far point r.

In hypermetropia parallel rays from infinitely remote objects form a virtual focus behind the retina, but if the grade be not too high, with the assistance of the accommodation, the eye sees at an infinite distance. In myopia the action of the accommodation brings the far point still nearer the eye, and thus increases the defect of distant vision. When the ciliary muscle is completely relaxed, r is at its greatest distance; in order to see infinitely remote objects, parallel rays must be made divergent by a concave lens, and enter the eye in the same direction as if they came from r. Myopia then consists in an inability to distinctly see at an infinite distance; but near objects, within the range of accommodation, are recognized perfectly. The existence of myopia and its grade, may be determined by the test-letters of Snellen. The patient is directed to look at the card hanging on the wall, and read No. XX at 20′. If he cannot do this, weak concave glasses are placed before his eyes; if these improve his vision, then stronger ones are tried; perhaps he reads some of the larger letters which he was unable to make out with the naked eye; continuing to increase their power, those are found with which he reads No. XX. We have now the glasses which enable him to see infinitely remote objects, and their focal length increased by the distance they are held from the eyes, represents the grade of his myopia, that is, the distance of r from the eye. Stronger glasses than these render his vision indistinct. For illustration, without glasses, he sees No. C. With $-\frac{1}{48}$, he reads No. LXX. With $-\frac{1}{30}$, he makes out L, changing to $-\frac{1}{24}$, he reads No. XL. With $-\frac{1}{20}$, No. XXX. With $-\frac{1}{16}$, he clearly sees No. XX. This is the proper type for the emmetropic eye to read at 20′. No. $-\frac{1}{14}$ dims his vision; hence we determine that he has myopia, and that its degree equals $\frac{1}{17}$; r is 17″ from the anterior nodal point, allowing the glass to be held one inch from the eye. Now, if he has good powers of accommodation, he may see remote

objects equally well or better with glasses which are really too strong, because then the eyes are rendered hypermetropic, and the tension of the ciliary muscles overcomes this condition, just as it does in facultative H.; he sees a little better, because with tension of accommodation the pupil (which in myopes is large) is diminished in size, and the more circumferential rays are excluded. Hence, the weakest concave glasses which make No. XX distinctly seen at 20′, are the proper ones to neutralize his myopia and to indicate its degree; whether or not slightly weaker glasses will answer, can be determined simply by removing the lenses a little farther from the eyes; if vision be then equally good or better, weaker glasses must be substituted for the stronger ones. As it is desirable to save time, by determining approximately the proper focal length of the required spectacles at once, without going through the tedious process of trying many different numbers, the far point may be found with tolerable accuracy by directing the patient to read moderately sized print — No. V or VI Jaeger's test-type (somewhat smaller than the letters on this page), at the farthest distance from the eyes at which they can be sharply seen, (if the far point be very near the eye, still smaller print must be used.) The measure of this distance indicates with tolerable accuracy the grade of M. If this be 8″, then place before his eyes glasses — $\frac{1}{8}$. The patient will now read No. XX. If he cannot do this, in order to ascertain, without removing the glasses from the eyes, if stronger or weaker ones are required, place before them first weak convex glasses; if these make the vision still more dim, then try the addition of weak concave glasses; if No. XX be now easily read, the first glasses — $\frac{1}{8}$ are not quite strong enough and a higher number must be substituted. The refractive state of the myopic eye can be determined by the ophthalmoscope. As the retina is beyond the focus of the dioptric apparatus, there will be an inverted aerial image of the fundus oculi in front of the eye, at a distance proportional

to the degree of the myopia. Now the observer can see this inverted image. If he knows the adjustment of his own eye and its distance from the observed eye when in a state of rest, he has only to subtract his own adjustment from the distance of his own from the observed eye, and the difference represents the degree of myopia. For illustration, suppose the observer's eye is accommodated for a point 8″ distant, and it sees the inverted retinal image when 12″ from the observed eye, then $12'' - 8'' = 4''$. The focus of rays from the fundus oculi of the observed eye lies 4″ in front of the eye; the degree of myopia $= \frac{1}{4}$. Another method of determining the existence of myopia and its degree, is by what Dr. Knapp calls Ophthalmoscopic Optometry. (This method is applicable to ametropia in all its forms, and for measuring the elevations and depressions in the back-ground of the eye.) The examination of the erect image is made by holding the ophthalmoscope about an inch from the examined eye. If the observed and observer's eye be emmetropic, the observer sees the retina erect and sharply defined. The rays emerge parallel, and the observer, by relaxing his accommodation, unites these in his retina and sees an erect virtual image of the fundus. Now, if the observer, his eye being emmetropic, or made so by a proper correcting-glass, cannot get a distinct view of the retina of the observed eye, the latter is ametropic; the emerging rays are either divergent or convergent; they must be made parallel before entering the observer's eye. In hypermetropia, as previously explained, the emerging rays are divergent; to make them parallel, requires a convex lens; hence, if this renders the fundus still more indistinct, there is myopia, and concave glasses must be successively placed behind the opening in the ophthalmoscopic mirror until one is found which renders the erect image clearly defined. The focal length of this glass, increased by its distance from the eye, gives the distance of the anterior conjugate focus, which represents the degree of myopia of the observed eye, and this concave lens will be the proper one to correct the error

of refraction. As usually several lenses have to be successively applied before the proper one is found, Dr. Loring, of New York city, has devised an ophthalmoscope consisting of three rotating disks, each containing a number of convex and concave lenses, so that by simply rotating the disk with the finger, different lenses can be brought behind the opening in the ophthalmoscopic mirror without removing it from the eye. Dr. Knapp has improved on Dr. Loring's instrument, by placing two disks behind the mirror, one containing a number of concave, the other convex, lenses. By rotating one disk on the other, the combination is such, that a lens of any desired strength may be obtained in a few moments. This obviates the necessity of removing the instrument from its position to change the disks, as may be necessary in Dr. Loring's instrument, thus saving time and the annoyance to the patient of a more protracted examination. In testing the eyes for myopia, because there is more distinct vision with concave glasses, it must not at once be taken for granted that this anomaly exists, for in certain conditions of the emmetropic eye, as in diffuse opacity of the cornea, or an abnormally enlarged pupil, the contraction of the latter accompanying the tension of accommodation necessary to neutralize the effects of concave glasses, shuts out the peripheral rays, which fall on the retina in circles of diffusion, and thus renders the details of objects more sharply defined. So in spasm of the ciliary muscle, a concave glass overcomes the effects of this and makes distant vision distinct, although the eye at rest is actually emmetropic. Each eye should in all cases be examined separately, to ascertain the difference which may exist in their refractive conditions.

Comparative Frequency of Myopia in Different Classes of Society.

Near-sightedness is rarely seen in persons reared in the country, and who devote themselves to occupations requiring but

little exercise of sharp vision for small objects. Among this class, hypermetropia prevails to a much greater extent. M. is much more frequently met with in cities, particularly among the educated, intelligent classes. It is not equally prevalent in all countries. Donders says that "among the states of Europe visited by me, I, both in general life and in the cliniques, nowhere met with relatively so many myopes as in Germany." In the United States it is much more common in the Eastern and Middle States than in the West and South. The great number of persons in Boston seen wearing concave spectacles, is a subject of remark with many Southern and Western visitors to that city, and is often by them attributed to a *desire to appear fashionable*. The real cause of the great prevalence of near-sightedness in that city is undoubtedly the same as in the cities of older countries. As a nation or community becomes wealthy, refined, and elevated in social position, the inhabitants are more inclined to cultivate the intellectual faculties; hence, they spend much time in close study, requiring a great and prolonged tension of accommodation in reading, writing, etc. They usually sit bending over a desk, in a stooping position; the abdominal organs are compressed, preventing the free return of the blood from the head. The insufficient illumination at many schools and colleges necessitates the bringing of the eyes very near the book, so as to obtain a larger visual angle, and as the book usually rests on a desk or table, the head has to be bent over; this posture produces an increased flow of blood to the eyes, whilst the higher degree of convergence necessary causes an increased pressure of the lateral recti muscles on the equator of the globe, thus increasing the intra-ocular pressure. The congestion of the fundus oculi causes softening of the scleral tissue, which gives way under the increased pressure, and the organ is elongated backward (*posterior staphyloma*); the other portions of the sclerotic coat are supported by the broad muscles. The retina is then pushed backwards behind the focus of the dioptric apparatus. When

this condition once commences, all the causes which first gave rise to it, act with increased force. There is a greater stooping posture necessary, because the eyes have to be brought still nearer the object; an increased convergence is demanded, and the congestion of the fundus oculi increases; consequently, the softening processes progressively augment, causing the posterior portion of the sclerotica to yield more and more. Hence, myopia is usually progressive, particularly in its higher grades. There is a greater tendency to the development of this condition of the eye in youth from the causes above mentioned, because then, the scleral tissues are softer, and consequently more yielding than in later life. With the increase of age this coat hardens, becomes firmer and better able to withstand intra-ocular pressure; hence, it is rare that the posterior staphyloma giving rise to near-sightedness commences after the twentieth year of life. If great and protracted tension of accommodation, with stooping posture and strong convergence will, alone, give rise to the development of myopia, we should expect to find this anomaly of frequent occurrence among tailors, needle-women, embroiderers, lace-makers, and in other occupations involving similar conditions. But among these, M. is much more rarely developed than in the wealthier and more intellectual classes. The comparative exemption of the former class is, no doubt, partly due to the fact that they do not engage in these occupations until the age of sixteen or eighteen years, when the scleral tissue has become sufficiently firm to resist the additional intra-ocular pressure; while, in the latter class, myopia begins to develop in children while attending school. Among the latter it is probable, too, that another factor is brought into action. It is a well-established fact, that when the mind is intensely engaged in thought an increased quantity of blood is thrown to the brain, and, as a consequence, more blood enters the eye, and the congestion of the fundus oculi is by this cause still farther increased. Near-sightedness is very prevalent among students of uni-

versities and colleges. Mr. Ware found it particularly so at Cambridge and Oxford. In the latter institution thirty-two out of one hundred and twenty-seven of the students wore concave glasses. It would be a matter of much interest, and tend to the advancement of ophthalmological science, if, in the different institutions of learning, accurate statistics were kept of the number of students wearing concave glasses, in proportion to those having normal vision, and to ascertain whether myopes are not usually more studious, thus exercising, to a greater degree, both tension of accommodation and their intellectual faculties.

While these pages were passing through the press, a copy of the "Medical Record" was received, containing the following summary of the results of examinations made of a large number of children attending school:

"*Examination of the Eyes of School-children.*—One of the most interesting as well as important of the papers read at the recent meeting of the American Social Science Association, at Detroit, was by Dr. Webster, assistant to Prof. C. R. Agnew, of this city, and contained the statistical results of examinations made of the vision of school-children in Brooklyn, Cincinnati, and New York. In these cities, the eyes of two thousand eight hundred and eighty-four scholars of both sexes, ranging in age from six to twenty-six years, had been examined, and the conditions as to refraction and disease noted. At the same time, the state of the school-rooms, as regards light, desks, heating, and ventilation, was observed, as well as the length and distribution of the time devoted to study, and other facts which might affect health.

"Drs. Ayres and Williams examined the eyes of one thousand two hundred and sixty-four scholars in Cincinnati, one-third of whom attended district schools, one-third the intermediate, and the remainder were pupils in the normal and high schools. In the district schools 13·3 per cent. were near-sighted (11·3 per cent. of the boys and 15·3 per cent. of the girls). In the intermediate schools 13·8 were near-

sighted (9·5 per cent. of the boys and 18·1 per cent. of the girls). In the normal and high schools 22·8 per cent. were near-sighted (22·2 per cent. of the boys and 23·2 per cent. of the girls).

"Drs. Prout and Mathewson examined the eyes of six hundred students at the Polytechnic, in Brooklyn, all of whom were boys, two hundred and eighty-four belonging to the academic and three hundred and sixteen to the collegiate department. Of the former 9·2 per cent. were near-sighted, and of the latter 21·8 per cent.

"Dr. Cheatham examined the eyes of one thousand and twenty boys in the College of the City of New York; six hundred and seventy belonging to the introductory class, two hundred and ten to the freshmen, one hundred and ten to the sophomores, and thirty to the juniors. In the introductory class, which is made up entirely of students who have passed the public schools, 21·9 per cent. were near-sighted; of the eyes of the freshmen, 26·2 per cent. were near-sighted; of the sophomores 22·7 per cent., and of the juniors examined 50 per cent. were near-sighted, although of the juniors the number examined was too small to be of any scientific value.

"The tables which were based on these observations show that staphyloma posticum, one of the gravest organic changes in progressive near-sightedness, increased from 0·5 per cent. in the district schools to 7·6 per cent. in the intermediate, and 10·4 per cent. in the normal and high schools. In one of the large schools, in which a careful ophthalmoscopic examination was made of every scholar, out of about one thousand scholars the eyes of seven hundred and three were found to deviate otherwise than in refraction from the normal standard."

Since it has been definitely determined that near-sightedness does not depend on a greater degree of convexity of the cornea, some have thought that it may sometimes arise from an increased convexity of the crystalline lens (*plesiopia*),

induced by long-continued tension of accommodation, so that when the ciliary muscle is relaxed the crystalline does not return to its normal form when at rest. Stellwag, after expressing doubts as to excessive curvature of the cornea ever being the cause of true myopia, adds: "On the other hand, increased convexity of the crystalline can scarcely be denied to be a cause of myopia." But this form of near-sightedness "always remains of a low grade." Donders at one time entertained similar views, but after a more extended observation, embracing more than twenty-five hundred cases of near-sightedness, in all of which he was able to determine the cause, says: "No cases remained in which I was obliged to take refuge in extraordinary convexity of crystalline lens."

Congenital Predisposition to Myopia.

Myopia is almost universally regarded as a hereditary disease. The hypermetropic eye never, and the emmetropic one rarely becomes near-sighted without a predisposition to it, derived from ancestors. "But that having once occurred, the M. is often transmitted as predisposition to posterity, and under fresh exciting causes is developed to its higher degrees. Thus the hereditary principle accumulates in the posterity, the effect of the causes repeated in every generation." (*Donders.*) When a young person with M. presents himself for examination, almost invariably, when questioned, he will reply that one or both of his parents and grandparents had a similar affection, and that some of his brothers or sisters are also near-sighted. In the South and West the few cases seen are in certain families, and generally several members are likewise afflicted. When once developed in youth, even in a slight degree, its tendency is to increase; the prevailing opinion that it diminishes with age is incorrect. All eyes, the myopic as well as the hypermetropic and emmetropic, undergo the usual senile changes, and if in middle life the M. be still of low degree, these changes will cause *p* and *r* to recede, but the abnormal elongation of the eye does not diminish.

Myopia at a Distance.

It sometimes occurs that persons have normal near vision, but are unable distinctly to see remote objects.* Græfe accounts for this by supposing that in the effort to relax the accommodation for distant vision a spasm of the ciliary muscle takes place, preventing the lens from assuming its normal flattened condition when the eye is at rest. Donders states that he has never seen a case in which this condition of spasm existed, but has always accounted for M. at a distance by finding an abnormally enlarged pupil, which permitted large circles of diffusion from the peripheral rays. In the case mentioned in the foot-note, the patient, by looking through a small opening, saw No. XX at 20′, which would not have been the case had the lens been too convex.

Anatomical Changes in the Fundus Oculi in Myopia.

Since the invention of the ophthalmoscope, changes taking place in the fundus of the eye can be detected, and their progress carefully observed. By means of this instrument it is clearly shown that the myopic is a *diseased eye*, and that the grade of the M. is proportionate to the degree of extension caused by these morbid anatomical changes; hence, myopia and staphyloma posticum are nearly synonymous terms.

* An interesting case of myopia at a distance came under my observation in the latter part of the year 1872. A gentleman, some thirty years of age, consulted me for this affection. He read No. 1 Jaeger at 8″ and 16″ with the naked eye, but at 3′ was barely able to make out No. XX Snellen test-types. At 20′ he read No. CC. With glasses — $\frac{1}{18}$ he read No. XX at 20′; by looking through a small hole in a blackened metal plate, he read No. XX without glasses. He stated that when a youth he put on concave spectacles and wore them because he thought it fashionable, although his sight was perfect without them. For distant vision he had found it necessary to gradually increase the strength of his glasses, but for near objects he did not use them, and could read and write perfectly at the usual distance for emmetropic eyes. His occupation was that of a book-keeper. His eyes were morbidly sensitive to a very strong light, and in attending the theatre he looked constantly through an opera-glass, but suffered much the next day.

The extension of the posterior part of the sclerotic coat is generally uniform in all its parts; the globe then exhibits a regularly ellipsoid form. The extension takes place at the expense of the thickness of the scleral tissue; consequently, in high degrees of staphyloma posticum, this coat becomes, in the region of the posterior scleral pole, as thin as paper. Sometimes, when the eye is turned far inwards, the dark pigment of the choroid can be seen shining through the thinned scleral tissue, giving it a dark appearance; and when the eye is removed from its orbit, light passing into it through the pupil can be distinctly seen shining through the atrophied part of the sclerotic coat. As the firm, dense sclerotica gives the eye its form and retains the interior structures in position, it follows that if this be at any part extended, the parts lying adjacent will also be correspondingly changed in position and similarly extended. Thus we find that the choroid coat also becomes extended and atrophied, particularly on the outside of the optic disk, with diffuse atrophy in other places, accompanied by morbid changes in the region of the yellow spot. While the sclerotica attains its greatest thinness around the posterior scleral pole, the choroid becomes thinnest around the outer edge of the optic disk, forming, in advanced degrees of myopia, a white, shining, concentric disk, resembling in shape a meniscus. At a little distance from the edge of the optic papilla, the sclerotic coat receives the outer sheath of the optic nerve and is strengthened by this coalition. The scleral coat around the nerve entrance, before it receives these additional fibres, is thinner, consequently more distensible. The choroid is firmly attached to and rests on the inner sheath of the optic nerve, which is supported by the thin sclerotic coat, and is prolonged among the nerve tissues, to which it is also adherent. The thinner and less resisting part of the scleral coat and inner sheath of the optic nerve, immediately around the disk, give way, and the choroid lying on it is distended; the pigment cells are obliterated,

and the chorio-capillaris no longer carries red blood, and there remains the marbled-white crescent-shaped atrophy. If the distension extends entirely around the disk, the atrophic crescent becomes annular. The extension of the parts surrounding the optic nerve entrance enlarges the size of the blind spot, by increasing its non-sensitive nerve surface. In myopia the retina undergoes fewer marked changes than either the choroid or sclerotica. The position of the yellow spot is changed; it approaches the posterior scleral pole, so

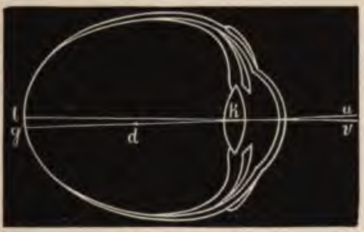


Figure 64.

that the visual line more nearly corresponds with the ocular axis. This is shown in Fig. 64, after Donders. It will be seen that the visual line *l v* forms a very small angle with the long axis of the cornea, *a g*. Compare with Figs. 22 and 62, on pages 74 and 193.

In very high degrees of near-sightedness, the fovea centralis may even pass to the inside of the posterior scleral pole; then, the axis of vision cuts the cornea outside of its zenith. The apex of the scleral ellipsoid is generally found to be situated at or near the region of the yellow spot; hence, this part of the retina is more extended; consequently, more liable to morbid changes, causing the functions of the retina to suffer, which is particularly noticed in central vision. "It is easy to see, although it has not been proved by accurate microscopic investigation, that under such extension the outermost layer, which consists of radiatingly placed very small bulbs, must suffer; that these bulbs at least must be separated, irregularly distributed, and made oblique,

and that they must easily be actually destroyed. In other parts, too, of the retina, the rods and bulbs, as we have seen, appeared to be more separated." (*Donders.*) Nearly always with great development of posterior staphyloma, inflammatory symptoms supervene, causing morbid deposits, hemorrhage in the vitreous, sub-retinal effusions, etc. The vitreous humor loses its gelatinous form, and becomes fluid, and more or less turbid, thus diminishing its transparency.

Vision of Near-sighted Persons.

It often happens in the lower grades of myopia, where the error of refraction does not amount to more than $\frac{1}{18}$ or $\frac{1}{20}$, that the existence of it is unknown to the person himself, and he only discovers the defect by accidentally trying on concave glasses, when he finds that he can distinctly see objects at much greater distances than with the naked eye. If the degree of M. remains stationary, he will probably be able to read fine print without convex glasses at fifty-five or sixty years of age. The tardy recession of the near point will compensate for the diminution in the range of accommodation from senile changes, until a late period of life. Persons with myopia of higher grade and good range of accommodation, have a habit of bringing small objects much nearer the eyes than there is any necessity for, and, as it is often inconvenient to elevate their books or work sufficiently, they habitually bend the body so as to assume a stooping position, the more so the higher the degree of near-sightedness. The pupils of myopes are almost always larger than in emmetropic eyes, and as distant objects are seen in circles of diffusion, they acquire the habit of partially closing their lids, in order to shut out as much as possible the diffusion circles from the ununited peripheral rays. This, with wrinkling of the skin of the forehead, gives the features a peculiar expression, by which the myope may easily be recognized; this habit is often kept up even after the error of refraction is entirely neutralized by concave glasses, and

the necessity for using the lids as a stenopæic apparatus no longer exists. In low grades of myopia, when the far point is less than 14″, and in medium degrees when *r* lies between 6″ and 14″, the vision within the range of accommodation is just as good as it is in the emmetropic eye; beyond the far point, all objects are seen in diffusion circles. As small objects, to be sharply defined, are held much nearer in myopic than in emmetropic eyes, the visual angle under which they are seen is proportionally larger; consequently, a larger image is formed on the retina, thus impressing a larger number of percipient elements. In addition to this, myopes having larger pupils, see with a more feeble illumination; they prefer for reading, fine print; they write a fine hand, make small stitches in sewing, embroidery, etc. While they see small near objects in a feeble light, on the contrary, distant vision is improved by a bright illumination, because the strong light contracts the pupil, and thus diminishes the size of the diffusion circles. For this reason, *r*, in myopes, is considerably removed, by looking through a small hole in a blackened card or metal plate. When the degree of myopia is greater than $\frac{1}{6}$, there is generally more or less disturbance of near vision; indeed, considering the morbid changes which have taken place at the fundus of the eye, and which are still progressive, it could scarcely be otherwise. The free use of the eyes, in looking at small objects, produces a feeling of tension, and they become painful; this condition is often followed by redness of the conjunctiva, and an increased flow of tears. Muscæ volitantes (floating dark spots) make their appearance in the field of vision; although, under certain circumstances, these can be seen in healthy eyes, as stated in the chapter on Entoptic Phenomena, in very high grades of M., they are larger, more numerous, and are constantly in the visual field. Their increase in size and numbers is caused by morbid changes in the vitreous, and when they seriously disturb vision, the ophthalmoscope generally reveals turbidity of this portion of the refractive media.

The constant appearance of floating bodies is a very alarming symptom to myopes, particularly if they allow the mind to be continually fixed on the subject. Donders says: "I have seen instances in which anxiety about muscæ volitantes amounted to true monomania, against which all reasoning and the most direct demonstrations were in vain." Other subjective symptoms appear, known as photopsia; they consist of sparks, luminous chains, flashes of light, brightly illuminated white or colored rings, and they often appear in the field of vision, more frequently seen in darkness than in daylight, and are very alarming to the sufferer. Their appearance is an indication that serious morbid changes have taken place in the fundus of the eye, and that true amblyopia is rapidly approaching; vision, however, may still remain tolerably uniform for a long time, particularly if great care be exercised in the use of the eye, and all excesses and irregularities of habits are avoided. In high grades of near-sightedness there is no distinct vision beyond a few inches from the eyes, without neutralizing glasses; consequently, the myope cannot fix the countenance of a person with whom he is conversing. He gazes, as it were, into vacancy. As he cannot see the ground distinctly, he walks in a careful, hesitating manner; hence, he has a peculiar gait by which his infirmity may often be recognized. As a consequence of the morbid changes and great extension of the retina in the region of the fovea centralis, sharp central vision is greatly impaired; the cones become irregularly separated, some are oblique, the functions of others impaired by morbid deposits; hence, straight lines often appear irregularly curved, but parts of words or letters are seen, or some even may be entirely absent. The myope now sees very small letters better than larger ones, because the smaller retinal image covers fewer of the displaced or disorganized sensitive nerve fibres, or, is formed on some part of the yellow spot that has undergone fewer morbid changes. These disturbances of central vision usually first appear in one eye, but it is not long

before the other is similarly affected. The greatest apprehensions of total loss of direct vision will, in all probability, be sooner or later realized.

Insufficiency of the Internal Recti Muscles — Muscular Asthenopia — Diverging Strabismus.

For binocular vision, the eyes must converge so that the visual lines meet at the point of fixation; hence, the nearer the object is to the eyes, the greater must be the degree of convergence. In the higher grades of myopia, small objects have to be held much nearer the eyes than in emmetropia, consequently, they must converge more; this necessitates an increased action of the internal recti muscles; more actual energy is required to adjust the eyes for the binocular near point, and more potential energy is necessary in order to keep up the proper adjustment for long-continued near vision. Owing to the ellipsoid form of myopic eyes, the antero-posterior diameter is elongated; the position of the centre of motion is relatively moved forwards on the visual axis; so that it is farther from the posterior surface, and also from the anterior surface of the eye; hence, to produce the same amount of changes in the direction of the ocular axes, or, in other words, for equal degrees of rotation, greater excursions, both of the apex of the cornea and of the posterior scleral pole, are necessary. In the higher degrees of myopia, the yellow spot is drawn towards the posterior scleral pole, so that the visual line passes through the cornea very near its apex, or even to its temporal side; this of itself renders a much higher degree of excursion of the ocular axes necessary for equal distances of the point of fixation than in emmetropic eyes; but as in myopia, p is much nearer the eye, the convergence must be proportionally greater. For these reasons, it is evident that in high degrees of M. a much greater amount of exertion is demanded of the internal recti muscles, to produce and sustain the required degree of

convergence for binocular vision of small objects; the higher the degree of near-sightedness, the greater is the demand for increased action and strength of the muscles of convergence. Their power is often insufficient to converge the eyes to the binocular near point, or the muscles may produce the required convergence, but are deficient in the potential energy necessary to maintain the adjustment. "*Insufficiency of the inward movement* we assume, when the visual lines cannot be brought to intersect at a distance of 2″·5, at which they cut one another under an angle of about 51°." (*Donders.*) If the myopia has developed slowly, the internal recti muscles may have gradually increased in size and strength sufficiently to perform the excessive labor demanded of them; but often, particularly if the development has been rapid, there is a want of power of one or both of these muscles to long maintain the required tension; when one fails, it permits the external rectus to turn the eye outwards, and the object is then seen double. When once the insufficiency of an internal rectus has manifested itself, it does not readily regain its strength, even after a considerable period of rest; and it becomes less and less able to sustain prolonged action, until finally the insufficiency becomes so annoying that artificial assistance must be rendered, or binocular vision given up. The weakness of the muscle can easily be shown by directing the patient to read fine print, held in the horizontal plane, or a little lower, before the eyes, and watching the result; soon one eye will be seen to waver for a moment, and then deviate outwards. Another test is to place a weak prism before one of the eyes when they are adjusted for near vision, with its angle up or down. Few eyes can overcome a prism of 2° with its refractive angle upwards or downwards, so as to fuse the double images, one of which will appear in a vertical line above the other. Single vision once removed, a muscle overstrained gives way, and seeks an equilibrium with its opponent according to the relative strength of the two. When normal eyes are adjusted for parallel rays, only very weak prisms,

with their angle outwards, can be overcome; but with the angle turned inwards, the internal rectus can overcome a prism of from 20° to 25°, so as to fuse the double images; but this difference diminishes as the object approaches the near point, where the power of abduction and adduction is nearly equal. Here, if there is an insufficiency of one internal rectus muscle, the extent of it can be found by placing before one of the eyes a weak prism with its angle up or down, while looking at a small ink spot on a piece of paper; soon the weakened muscle will waver, then give way, and the eye will turn outwards. There will be seen two objects some distance apart laterally, but in different planes. Another prism, with its angle outwards, that will make these images stand in a vertical line one above the other, represents the degree of the insufficiency.

The power of convergence is considerably greater when the eyes are directed below the visual plane, and gradually diminishes as they are turned upwards, hence, the binocular near point is farther from the eyes, when they are elevated considerably above the visual plane. It is a little nearer below than when the visual lines rest in this plane. The disturbing symptoms in insufficiency of the internal recti muscles depend on exhaustion and fatigue from overstrained muscular tension, in maintaining for a length of time the proper degree of convergence for near vision of small objects, causing nervous and vascular excitement. There is no deficiency in the action of the ciliary muscles, for they can adjust the eyes in monocular vision to a point considerably nearer than the point indicating the maximum degree of binocular convergence. In fatigue and giving way of the muscles of accommodation, the borders of letters widen out and become indistinct; but in muscular asthenopia, the letters overlap or are seen double, showing that the accommodative adjustment is still perfect, but that the visual lines are not directed to the same point. There is a tendency to hold the book or work as far from the eyes as possible, in order to diminish the

degree of convergence, also to hold the object a little on the side of the eye having the weaker internal rectus muscle; but, in spite of these efforts, the eye finally deviates outwards, and relief is obtained by excluding it, and using but a single eye for near vision. Double vision is much less annoying to the myope than to the hypermetrope, owing to the fact that the retinal images are so diffuse in the deviating eye that physical exclusion is much more easily attained; the higher the degree of myopia the easier it is to withdraw the attention from the images formed on the retina of the deviating eye. Insufficiency of the internal recti muscles is said to be hereditary; many members of certain myopic families suffer from it, while other families, having equal or higher grades of near-sightedness, are exempt. Another cause of muscular asthenopia is a great and sudden disturbance of associations which should exist between the innervation of the ciliary and the internal and external recti muscles: this disturbance is particularly manifested when the posterior staphyloma has so rapidly developed that relative convergence and relative accommodation have not had time to adapt themselves to the changed conditions of association.

Divergent Strabismus.

As already stated, hypermetropia is the cause of a large majority of the cases of convergent squint. As myopia is a condition of the eye exactly the reverse of hypermetropia, we find that most of the cases of divergent squint are the result of this opposite condition of the eyes. In H. the accommodation is in excess of convergence, for when the visual axes are parallel and the convergence = 0, a certain amount of accommodation is necessary for distinct vision, and for every degree of convergence there is an excess of accommodation. When the binocular accommodation has reached its maximum, the positive part of relative accommodation soon fails to keep the accommodative adjustment within the line of relative accommodation. The effort causes the

ciliary muscles to tire from excessive labor, and accommodative asthenopia is the result. There is an inclination to converge more, so as to obtain the benefit of relative accommodation; this can only be accomplished by causing the visual lines to cross each other at a nearer point than the one of binocular fixation; and as there still remains actual and potential energy of the internal recti muscles, the squint is the result—binocular indistinct is sacrificed to monocular distinct vision. Now, in myopia, when the eyes are directed to the far point, accommodation = 0; but then, there is convergence equal to the degree of myopia, and this excess of convergence continues for every point on the line of binocular distinct vision. When the eyes have reached the maximum state of convergence, the potential energy of the internal recti muscles is soon exhausted; one tires, gives way, and the eye turns outwards. There still remains more or less of the power of accommodation. In H., the accommodation is in excess of convergence; in M., the convergence is in excess of accommodation. In each, within the range of binocular vision, the relative associations for a time compensate for the difference of innervation between the lateral recti and ciliary muscles; but when the limits exceed the compensating power of relative association, there ceases to be distinct binocular vision, or it is only attained by excessive muscular tension, leading to asthenopia and its attending symptoms. As soon as the object is brought nearer than the extreme limit of convergence in binocular vision, relative diverging strabismus takes place, and this occurs even if there be no actual insufficiency of the internal recti muscles. Dr. Theobald has made "an endeavor to show that insufficiency of the internal recti muscles and myopia have been erroneously associated; and that the muscular asthenopia of myopia is not the result of such insufficiency, but of the anomaly of refraction."

He says:* "This assumption of Donders, together with the test of Von Graefe, which I have described, are chiefly

* American Journal of the Medical Sciences for January, 1874.

responsible for the generally adopted belief in the association of insufficiency of the internal recti muscles with myopia. To account, however, for the symptoms which Donders has described, no such assumption is necessary. They are, indeed, exactly such as we should anticipate from the disturbed relation between convergence and accommodation, which, as I have before stated, exists in myopia as well as in hypermetropia. In hypermetropia, accommodation is in excess of convergence. When the eyes are used, especially for near work, asthenopia ensues; the ciliary muscles soon become tired and give way, and the sight grows indistinct. A convergent squint, by neutralizing the excess, may do away with these symptoms. In myopia, convergence is in excess of accommodation. Asthenopia, attended by giving way of the internal recti, is the result. As in hypermetropia there is no actual weakness of the ciliary muscles, so in myopia there is no real insufficiency of the internal recti. It is, in each case, the muscles which work in excess that evince such signs, and, as in the former condition an effort is made to neutralize this excess by a convergent squint, so in the latter is it accomplished by a divergent squint."

It is undoubtedly true that it is owing to errors of refraction that in H. excessive action of the ciliary muscles is demanded, and in myopia great tension of the internal recti muscles; and while in each of the above-mentioned conditions the muscles may have even more than normal actual and potential energy, yet there is a real insufficiency to perform the excessive labor demanded of them, in order to neutralize the anomalies of refraction arising from the optical defects in the construction of the eyes.

As the far point of binocular vision is nearer than the monocular far point, when the myope desires to see objects situated farther than the binocular far point, he does so by diverging the visual lines so that they cross beyond the objects. This is *absolute divergent strabismus*. While convergent squint usually appears in childhood, divergent stra-

bismus is rarely developed until a more advanced age; the latter is usually connected with progressive myopia, which is seldom found in early life. Donders states that 90 per cent. of the cases of relative divergent strabismus have their origin in myopia.

Treatment of Myopia.

The question very naturally arises, Can myopia — or near-sightedness — be cured? The answer must unhesitatingly be in the negative. It is simply absurd to suppose that the dense, firm, and but slightly elastic fibrous tissues, forming the sclerotic coat of the eye, after softening and extension, at the expense of its thickness, can ever be restored to their normal condition, so that the softened and extended fibres will contract, and bring the posterior part of the sclerotica back to its original form and thickness, replacing the retina again in the focus of parallel rays when the eye is at rest. This change never takes place. The popular idea that myopia diminishes with age is incorrect. It is true, that in low grades of non-progressive near-sightedness, as $\frac{1}{20}$, $\frac{1}{18}$, or less, the inevitable senile changes which diminish the refractive powers of the dioptric media may neutralize the effect of the changed position of the retina, and enable slightly myopic eyes to dispense with convex glasses for near vision, until a late period of life.

It is for this reason that Donders gives the preference to the slightly myopic eye, because he thinks that the indistinctness with which distant objects are seen in early life, is more than compensated by the ability to read and write at a later period of life without the use of convex glasses. The actual myopia, however, does not diminish; there is scarcely any recession of the far point of distinct vision, because the increased distance at which the myope could otherwise see, is neutralized by the diminution of the transparency of the refractive media and by the blunted sensibility of the perceptive elements of the retina. It has been attempted to diminish the posterior elon-

gation of the eyeball by requiring the myope to hold his book, paper in writing, or work, at a greater distance. Desks with apparatus, have been constructed to keep the head elevated, and gradually to increase the distance at which small objects are seen; and after a few weeks' practice the myope is often able to read at a considerably greater distance, and he thinks that the myopia has diminished; but he forgets that the degree is determined by the far point of distinct vision, and for points nearer than this, the exercise of accommodation is brought into action. The emmetrope ordinarily holds his book ten or twelve inches from his eyes; but if he accustoms himself to read 15″ or 18″ distant, he simply reads with diminished accommodation; so with the myope, if he increases the distance at which the book is ordinarily held, he only sees with less exercise of the accommodative power. The emmetropic eye still remains emmetropic, and the far point of the myopic eye is unchanged in position; the grade of the myopia does not diminish, but less accommodation is demanded. While this plan of treatment does not lessen the degree of the myopia, yet it has most excellent effects in staying the progress of the organic changes taking place at the fundus oculi. Holding small objects farther from the eyes diminishes the convergence, and thus removes a part of the pressure of the lateral muscles on the globes, while keeping the head erect lessens the flow of blood to the already congested tissues, and thus retards the softening processes upon which the giving way of the scleral tissue mainly depends. For these reasons the myope should always accustom himself to hold his book or work as far as possible from the eyes. Formerly, myopia was thought to be caused by an excessive convexity of the cornea, and systematic efforts were made to lessen this by compression; but now, since it is universally acknowledged to be dependent upon a giving way or extension of the scleral tissue, we can readily see that such treatment is not only useless, but injurious, because the pressure tends to increase the

posterior elongation of the eyeball. The cornea, as is now known, is a little flatter than in the emmetropic eye, and even if it could be made more so, no advantage would be gained, beyond what can be obtained from neutralizing glasses. Extraction of the crystalline lens has been suggested; but few patients could be found who would submit to it, and still fewer ophthalmic surgeons who would have the hardihood to recommend so hazardous an operation. Even if successfully performed, the accommodation would be destroyed, and the only advantage gained would be somewhat larger retinal images obtained by neutralizing glasses. Myopia then, is incurable, and only the lower grades are neutralized by the compensation of senile metamorphosis at a later period of life. Donders says: "In young persons, on the contrary, I have never established the fact of any diminution of the myopia. When the latter appeared, on superficial observation, to have taken place, spasm of the accommodation had been in operation." As the eye cannot be restored to its former condition, the treatment must consist in endeavoring to arrest the progress of the abnormal changes, and at the same time to render vision easy and comfortable, by neutralizing the errors of refraction, as far as it can be done without injury to the eyes, and to increase the distance of the near point, in order to diminish the excessive convergence, and consequently lessen the tension of the internal recti so as to remove the strong pressure of the lateral muscles on the globes. Where a predisposition to myopia exists, one of the chief exciting causes is long-continued tension of accommodation for near vision of small objects. Simple tension of accommodation of itself does not give rise to myopia, and it is chiefly through accompanying conditions that the morbid changes are developed. Children at school are often placed in a bad light, the desks are too low, and the body is bent forward; they thus acquire an habitual stooping position, and they are inclined to bring the eyes too near the book or paper on which

they are writing; this requires a strong convergence for binocular vision, both causes giving rise to congestion of the fundus oculi. This is particularly exemplified in writing. If one enters a school of children while they are engaged in writing, he will see nearly all of them, when the teacher has failed to give proper instructions, bending over their desks with their eyes in close proximity to the paper, and many assume an awkward, constrained position, not unfrequently with their heads resting on the arm and looking obliquely at the paper. While children with eyes not predisposed to near-sightedness may assume these positions with impunity, others having the hereditary predisposition, have the morbid changes developed, and when once they appear their tendency is to increase. At first, the near approach of the eye to the work was unnecessary, and only an acquired habit, but after the posterior staphyloma has once become developed, the pupils feel an actual necessity for the nearer approach of the eyes to small objects looked at; and this necessity increases as the disease progressively develops; hence, the causes which first gave rise to the morbid changes continue to act with more and more force, until finally the integrity of the function of the eyes is seriously threatened. Teachers, and others having charge of children and young persons who exercise their eyes with objects requiring great tension of accommodation, should require the books, work, etc., to be held at a proper distance, and the head to be held erect; and, if there appears to be a tendency to the development of near-sightedness, special care should be exercised that these rules should be enforced, and if possible near vision for a time given up; or, if this cannot be complied with, the eyes should be frequently rested by looking for a few minutes at distant objects; here the desk and apparatus for keeping the head elevated will be found particularly useful, so as to keep the objects as far as possible from the eyes, and thus diminish the convergence. When the morbid changes have commenced, the myope should at once be apprised of the serious

nature of his affection, and instructions given him to exercise great care to avoid excesses in eating and drinking, irregular habits, etc., and particularly to avoid reading in a recumbent position,—a habit to which young persons are much addicted. In reading, the head should be erect, and it is better that the book should be held before the eyes nearly vertical.

By Means of Concave Spectacles.

One of the most important remedial measures in the treatment of near-sightedness consists in the proper adaptation of concave glasses; the patient should never be allowed to select these himself, because he almost invariably chooses those which are too strong, and consequently injurious. In low grades of myopia, as $\frac{1}{18}$, $\frac{1}{20}$, or less, neutralizing glasses need only to be used in obtaining a more distinct view of distant objects, and for this purpose eye-glasses may be temporarily held before the eyes. For viewing scenery, or in attending theatres, or lectures in which diagrams, apparatus, etc., are used for illustrations, and on other occasions in which it is desirable to see at an infinite distance, spectacles which remove r to an infinite distance may be worn, but in attending to the ordinary affairs of life they can easily be dispensed with. Many persons, however, having once worn concave glasses, and experienced the satisfaction of distinct distant vision, are unwilling to do without them, and wear them constantly out of doors. In the low degrees of M. of which we are speaking, their use is entirely unnecessary in near vision, and had better be dispensed with, for vision of small objects is distinct at 10″ or 12″ from the eyes. If used to see at short distances, they are liable to create a disturbance of the relations which should exist between relative association that may give rise to progressive M. Near-sighted young persons are very apt to select occupations which require sharp vision of small objects, as engraving, watch-making, etc., and think they are particularly suited

to such callings, because they can see small objects with less effort than those having emmetropic eyes. This is a great mistake, and they should always be warned against such undertakings, and advised to select occupations that do not require great tension of the accommodation. In higher degrees of near-sightedness, ranging from $\frac{1}{5}$ to $\frac{1}{8}$ or $\frac{1}{12}$, the use of neutralizing glasses cannot be safely dispensed with; it then becomes a question, What is the proper strength to adapt in each particular case? Donders's remarks on this subject are so appropriate, and so clearly expressed, that we give them space here: "The prescribing of spectacles for myopes is a matter of great importance. While emmetropic and hypermetropic eyes do not readily experience any injury from the use of unsuitable glasses, this may in myopes, particularly on account of the morbidly distended condition of the eyeball, and of the tendency to get worse, be very dangerous. There exists, in general, a dread of the use of too strong glasses. It is laid down as a rule: rather too weak, or no glasses, than too strong. In this rule the necessary distinction is lost sight of. Too strong glasses make hypermetropic eyes myopic, and myopic eyes hypermetropic. The rule, therefore, cannot be equally true for both. In fact, it is in general much less injurious to produce a certain degree of myopia than of hypermetropia, in which last particularly much is required of the accommodative power. The rule would therefore be more correctly stated thus: in hypermetropia we must beware of giving too weak, in myopia of giving too strong, glasses; a rule the second part of which we should especially insist upon. But even by this little is gained. Not using glasses, or using too weak glasses, may also be injurious to myopes. All the circumstances must therefore be studied, which can exercise an influence on the choice of glasses. It is difficult to reduce these to definite rules."

In medium degrees of myopia, with a good range of accommodation, as a general rule, the anomaly of vision may be wholly neutralized. While the far point is thus placed at an

infinite distance, work can then be held 10″ or 12″ from the eyes; this diminishes the convergence, and removes a part of the pressure of the lateral muscles, and at the same time diminishes the tendency to assume the stooping position, so as to bring the eyes near the work. In the higher degrees of M.—when greater than $\frac{1}{8}$—there is usually a diminution of the acuteness of vision. The distance at which very strong glasses are necessarily held from the eyes, causes the lessening of the size of the retinal images, and then there is a desire to bring the object nearer the eye, in order to obtain a larger visual angle; but without glasses, the convergence and tension of accommodation are still greater, with an increased tendency to the stooping position; hence, for near vision it is better to partially neutralize the error of refraction; for example, to select those glasses which remove the far point to 12″ or 18″; and when the myope desires to see at a greater distance, he can place before the glasses a lorgnette which removes r to an infinite distance. After the supposed proper glasses are selected, they should be submitted to the test of experience. If those prescribed are not pleasant, or if they give rise to symptoms of asthenopia, they are hurtful, and should be changed for others of different power. If none be found which render near vision easy, all work or occupations requiring sharp sight should be given up. In very high degrees of myopia strong glasses are unpleasant, because, owing to the extension of the eye, chiefly in the region of the yellow spot, while there is acute vision with the aid of spectacles at this place, the peripheral images are very diffuse. If the highly myopic person has not previously worn glasses, it generally creates too much disturbance of relative associations to completely neutralize the errors of refraction at once; it is better to begin with weaker ones, and gradually increase their strength from time to time, as the eyes become accustomed to the changed conditions of associations, until finally the proper ones can be worn without producing unpleasant symptoms or injurious disturbances. When there

is an insufficiency of one or both internal recti muscles, or muscular asthenopia, arising from a want of parallelism between the action of the ciliary and the internal recti muscles, recourse must be had to concave glasses, in order to increase the distance of the near point, and thus, by lessening the binocular convergence, relieve the overburdened muscles from the necessity of excessive action. The tension of accommodation is at the same time diminished. If there be errors of refraction giving rise to asthenopia, the lessening of the convergence once more places the binocular point of fixation at a position on the line of accommodation which re-establishes the accustomed relative associations, and vision then becomes easy and free from asthenopic disturbances. If, however, there be insufficiency of so high a degree that neutralizing glasses fail to give sufficient assistance to the strained muscles, further aid must be given by prisms with angles outwards. The strength of the prisms must correspond with the degree of insufficiency. If this be confined to one internal recti muscle, and a strong prism be required, as the latter, if it has a large angle, produces annoying dispersion of light, it is better to divide the required prismatic strength between the two eyes. The necessary concave glasses should be ground on the surfaces of the prisms, or the latter may be attached to the former by means of Canada balsam. Prismatic effects may be produced in simple spherical glasses by moving their axes nearer to or farther from each other than the mutual distance between the two pupils. Spherical glasses then act as prisms with curved surfaces. In actual or apparent insufficiency of the internal recti, the axes of the glasses should be greater than the distance between the pupils. The convergence is diminished, but the rays enter the eyes as if they came from a nearer point than the one to which the axes of vision are actually directed; the tension of the converging muscle is relieved, while, at the same time, the bending of the rays by the prism enables the book, work, etc., to be held at an increased distance from the eyes. As concave spherical lenses

ground on prisms are expensive, it is better, in prescribing them, to submit the combinations to the test of experience, by placing simple prisms in apposition with the spherical glasses, and changing the arrangements from time to time, if necessary, until those are found which are exactly suited to the case, when instructions may be given to the optician to unite the combinations to single glasses. In the lower grades of near-sightedness, with the advance of age, the range of accommodation often becomes greatly diminished; in such cases concave glasses may be needed for distant vision, and weak convex for reading, etc. In adapting spectacles to myopic eyes, particularly when high numbers are required, the rules given in the article on spectacles should be rigidly observed. As the visual lines should pass as nearly as possible through the axes of the lenses, it is evident that the same spectacles which are worn for distant vision would not be adapted for near work when there is great convergence of the visual axes; in the latter case the axes of the glasses should be nearer each other, and the connecting wire of the frames curved, so that the convexity inclines backwards, in order to bring the surfaces of the glasses nearly parallel with the planes of the pupils; this position causes the axes of the glasses nearly to correspond with the visual line. When, even after the application of concave spectacles combined with prisms, there is still a tendency in the eyes to diverge when directed nearer than a certain point on the line of vision, tenotomy of the external recti muscles has been recommended, in order to diminish their resistance to the free action of the internal recti. The amount of setting back of the former muscles should correspond to the insufficiency of the latter. Care should be taken that this diminution in the power of the external recti does not exceed the amount of voluntary adduction when the eyes are directed to the far point of distinct vision; otherwise, there will result converging strabismus. "Unfortunately, a correct estimation of the operative effect is very difficult, and it is doubtful if any ope-

rator can, with any certainty, fulfil these indications. Usually, only a better position of the eye is attained; binocular vision is rarely much improved, or the asthenopia much diminished. This is particularly true when excessive myopia is the chief source of the affection; for here, besides the muscular insufficiency, various other causes, not remediable by tenotomy, assist in producing the asthenopia. But in other cases the operation is rarely sufficiently indicated." (*Stellwag.*) If all these remedies fail, the weaker eye must be excluded from use, either by a shade or by a very dark-colored glass.

ASTIGMATISM.

In ametropia, as previously treated of (hypermetropia and myopia), it has been assumed that the refracting surfaces were spherical or rotated, and so placed with reference to each other that their axes were centred in a common straight line; that homocentric rays — either parallel or divergent — coming from a point, remained homocentric after refraction, and were directed nearly to a point on the visual axis; that all rays deviated by spherical aberration from points on the cornea, at equal distances from its axis, united in a point on the axis nearer than the principal focus; that monochromatic rays also had their point of union on the axis, but the red, being least refrangible, united beyond the principal focus, while the blue and violet rays, having the greatest degree of refrangibility, met nearer than the principal focus. Eyes having their refracting surfaces so perfectly formed and accurately centred, are never found. Ametropia exists in some of the meridians to a greater or less degree in all eyes; if one meridian be emmetropic, another may be either myopic or hypermetropic, or myopia and hypermetropia may exist in different meridians of the same eye. Hence, all planes of homocentric light entering the pupil have not a common focus. This want of symmetry of the dioptric system has received the name of *astigmatism*, "and signifies that rays derived from one point do not again unite into one point," as stated on page 69, under the head of Anatomical Construction of the Eyes, — but recapitulated here to make this chapter more complete in itself, — the anterior surface of the cornea, which is the chief refracting one, is not the section of an ellipse rotated, but rather the top section of an ellipsoid with three diameters, the longest of which corresponds with the ocular axis; the next in length is usually horizontal, and the shortest, vertical. The latter two are perpendicular to the former, and usually to each

other. This formation makes the vertical meridian of the cornea more convex than the horizontal one; consequently, rays passing through it in the vertical plane are united in a focus sooner than those in the horizontal plane. Similar inequalities exist in the two surfaces of the crystalline lens, but here the maximum curvature is usually horizontal, and the minimum vertical, so that the asymmetry of the corneal surface is partially neutralized by the asymmetry of the surfaces of the lens. In the lens the length of the radius of curvature often varies in the same meridian, and marked inequalities frequently exist in adjacent ones; these deviations cause irregularities in its surfaces, which give rise to irregular astigmatism, and are the usual causes of monocular diplopia, and polyopia, etc. The long axis of the cornea and the axis of the surfaces of the lens do not usually lie in the same line; the axis of the lenticular surfaces cuts the cornea at the temporal side of its summit. Frequently the plane of the equator of the lens is not parallel to the base of the cornea; hence, it has an oblique position, which would of itself produce astigmatic deviations of homocentric rays.* Contrary to what is usually the case, the maximum and minimum curvatures of the lens may fall in the same plane with the similar curvatures of the cornea,—in which case the combined abnormal deviations form the sum total of the astigmatism. The line of direct vision does not correspond with the long axis of the cornea, but the former cuts the latter inside of the zenith, and a little above its horizontal meridian. These deviations in the regularity of the curvatures of the different meridians of the chief refracting surfaces of the dioptric media, and the want of correspondence of their axes, are usually too slight to disturb the acuteness of vision, but when of a higher degree, the perfec-

* This result is easily proved by holding a strong convex lens in the rays of the sun, with a screen placed in its focus perpendicular to the axis ray. When the axis of the lens is in a line with the central ray of the homocentric bundle, the image will be round; but if the lens be placed obliquely, the image will be oval, and if the degree of obliquity be very great, the image will be drawn out into a line.

tion of the retinal image is seriously impaired. The anterior surface of the cornea, as heretofore stated, has a much higher refractive power than all of the other refracting surfaces combined; hence, variations in the curvatures of its different meridians produce greater disturbances to vision than similar inequalities in the surfaces of the crystalline lens.

In order to better understand the manner in which unequal refraction in different meridians causes astigmatism, it is well to describe the effect on two planes of homocentric light from a bundle of rays passing through a small round hole in a window-shutter in the direction of the prolonged visual axis; one plane passing through the meridian of the maximum, the other through that of the minimum curvature of the cornea. If a thin metal plate with two narrow slits cut in it, crossing and standing perpendicular to each other, be placed before the eyes, so that one slit shall correspond to each of the principal meridians, it will permit two planes of the homocentric bundle of rays to enter the eye. The vertical plane, passing through the maximum curvature of the cornea, will first meet at a point. If we imagine a screen held at this place, the horizontal rays not yet having united will form a horizontal line of light on the screen. A little farther back the still converging rays will be crossed by the rays of the vertical plane, which have already met and are now diverging; at a certain place these lines will be of equal length. Still farther back the horizontal rays meet in a point, and the vertical ones form a vertical line on the screen a little longer than the anterior horizontal one. The former is called the anterior focal line, the latter the posterior. The interval between the points of meeting of the two planes of light represents the focal tract. The point of crossing of the two lines of equal length is a little anterior to the middle of this tract, and is called the middle focus. The distance of the middle focus from the anterior focal line decreases as the difference between the two focal lines increases. We will now remove the plate from before the eye, permitting the entire bundle of rays to fall on the cornea, and trace the changes produced on it.

If we imagine a screen to be held in front of the anterior focal line, the bright spot will be of an oval shape, with its long diameter horizontal; the screen moving backwards, its eccentricity increases, until at the point of union of the rays in the vertical plane it will be drawn out into a horizontal line; passing backwards the image again becomes oval, but its eccentricity decreases, until, when at the middle focus, it will be nearly circular; after which it again becomes oval with its long diameter vertical; its eccentricity increases until, at the point of meeting of the rays of the horizontal plane, the crossed rays form a vertical line. Passing the screen still backwards, the bright spot again becomes oval with long diameter vertical. The length of the anterior focal line is to the length of the posterior focal line as the focal distance in the meridian of greatest curvature is to that in the meridian of least curvature.

At the middle focus, where the image appears nearly circular, there is the greatest concentration of rays with the smallest disturbance from circles of diffusion; consequently, if the eye can be so adjusted as to bring this focus on the retina, the most distinct vision will result. Only those rays passing through in the planes of maximum and minimum meridians of curvature fall on the long axis of the cornea; the others meet in an irregular plane, passing through the anterior and posterior focal lines. This is beautifully shown in an ingenious instrument devised by Hasner and Knapp.* It is now very easy to see why astigmatics find so

* As many have difficulty in comprehending the effects produced on homocentric rays passing through meridians of different degrees of curvature, to such I would recommend a very simple apparatus, which is easily and quickly made, and which gives a better and a clearer idea than can be obtained from figures. It is only necessary to take a thin piece of plank four and a half inches wide and eight or ten inches long, on the ends of which are nailed pieces four and a half inches square, — a common cigar-box, after removing the top and sides, answers the purpose. One end represents the cornea, the other the retina. On the outside of each draw diagonal lines from corner to corner, and through their points of crossing draw vertical and horizontal lines; on one end these will represent the vertical and horizontal meridians of the cornea. At each end

much difficulty in selecting spherical glasses. Owing to the length of the focal tract, it is almost a matter of indifference whether the adjustment for the middle focus falls a little nearer or farther from either of the focal lines, and astigmatics can see nearly equally well within certain limits with spherical glasses of different focal lengths. For the same reason, it is difficult for them to determine exactly at what

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make a small hole through the point where the lines cross, and pass through them a thread, tightly extended from one to the other, and kept in position by fastening the ends to a small strip of wood placed on the outer sides. This thread will represent the long axis of the cornea. Next make two holes in the horizontal line, one at each end, two inches from the centre. Pass a thread through these, and bring the ends through the central one in the opposite end-piece, and fasten. This thread represents the most external rays of a plane of light passing through the horizontal meridian of the cornea having the minimum curvature, and uniting in a point on the retina. Next make in the end representing the cornea, in the vertical line, two holes, each being one and a half inches from the centre. In the opposite end make a hole in the vertical line three-quarters of an inch above, and another the same distance below the centre. Pass through each of the latter two holes the ends of a thread, and bring the end from the lower hole to pass through the upper hole in the vertical line opposite, and the thread from the upper one in the former to the lower one in the latter, and fasten. This thread represents the most external of the rays in a plane of light refracted by the vertical meridian of the cornea. It will be seen that the threads placed vertically unite considerably in advance of the horizontal ones; they overcross, and the now divergent rays form a vertical line of light, passing through the point on the retina where the horizontal rays meet. Now, if a screen be placed perpendicular to the axis at the point of meeting of the vertically placed threads, the horizontal rays would make a horizontal line of light. The axis thread extending from the points of crossing of the two planes, represents the focal tract, or focal interval around which, at some point, all of the rays from every other one of the planes of homocentric rays would meet. A point on the focal tract, where the converging and diverging threads are equally distant from the axis, represents the middle focus. The form of the illuminated spots formed on a screen, held perpendicularly to any point on the long axis of the cornea, — represented by the axis thread, — can easily be found by forming an ellipse with maximum and minimum diameters corresponding to the distance between the threads at that point. It is now easy to understand why, when the eye in the vertical meridian is adjusted for a point of light, rays in the other meridians form on the retina a horizontal line of light, and when it is accurately adjusted for the horizontal meridian, there will be a vertical line of light from the divergent rays in the vertical plane.

point of adjustment vision is most distinct. As before stated, all eyes are astigmatic, but when the degree is so small as not to interfere with the acuteness of vision, it is called *normal regular astigmatism.* When of higher degree, — generally when greater than $\frac{1}{80}$ or $\frac{1}{48}$ — the acuteness of vision is impaired; and it then becomes *abnormal regular astigmatism,* and requires to be neutralized by cylindrical glasses. Generally, the meridian of maximum curvature lies nearly vertical, and the minimum, perpendicular to this,— consequently horizontal; but these may vary; they are sometimes found exactly the reverse, as was the case of Thomas Young, the discoverer of astigmatism. The maximum curvature may lie in any of the meridians of the cornea, and usually the minimum will be found nearly perpendicular to this. As the maximum meridian is usually vertical, it follows that most persons can distinctly see horizontal lines nearer than vertical ones; for when the eye is accommodated for the line in the vertical meridian, the focus of the horizontal lies beyond this, and when the accommodation is for the horizontal line, it is beyond the focus of the vertical meridian. At first thought, it would seem that the reverse of this would be the case,—that vertical lines would be seen nearer than horizontal ones,—but a moment's reflection will show that this cannot be so. The lines to be visible must have a certain breadth, and it is their breadth that determines the visual angle under which they are seen. Now, if the line be horizontal, its breadth lies in the vertical plane, and all rays in this plane are united sooner than those in the horizontal plane; consequently, the horizontal line is seen nearer than the vertical one. The circles of diffusion from the rays in the horizontal line in the corresponding plane cover each other. The same explanation applies to the greater distance at which vertical lines are seen. It is the position of the focus of rays coming from planes perpendicular to the plane lying in the length of the line that determines the distance at which the line is sharply seen.

Normal Regular Astigmatism.

There are various means of determining this condition of the eye. The test, by looking through a small hole in a blackened card or metal plate, has been explained on page 71. The point of light may be obtained by placing a metal cylinder, in the side of which there is a small round hole half a line or a line in diameter, over the flame of a lamp; the hole being covered with milk glass or a piece of white gauze paper. At a certain distance the hole appears round and sharply defined; on approaching the lamp, the bright point is elongated horizontally; beyond the accurately adjusted focus it is elongated vertically. By placing a convex lens of 8″ or 10″ focal length, these effects can be produced with but slight changes in the distance of the eye from the light. Most persons, by taking a very weak cylindrical glass of, for example, $\frac{1}{72}$, $\frac{1}{84}$, or $\frac{1}{96}$, and rotating it before one eye,—the other being closed,—can find some position of the axis in which vision is improved. Were the eye entirely free from astigmatism, cylindrical glasses in all positions of their axes would impair the acuteness of vision.

Abnormal Regular Astigmatism.

In abnormal regular astigmatism vision is always more or less defective, its acuteness varying with the amount of astigmatic deviations. Persons having abnormal astigmatic eyes always seek, and, indeed, require larger type in reading; they hold the print nearer the eyes, in order to obtain a larger visual angle, and thus increase the size of the retinal image, so as to impress a greater number of rods and cones. They also, like myopics and hypermetropics, partially close the lids, in order to shut out a portion of the more peripheral deviating rays which greatly increase the disturbance of vision. There are many methods of ascertaining the existence of abnormal regular astigmatism, and of determining its degree. The test of Snellen, which consists of black lines radiating

from a central point, are in general use. Those devised by Dr. Green, of St. Louis, are preferable, and are represented in Fig. 65. Figs. 66, 67, 68, 69, and 70 are also selections from the test-objects of Dr. Green. Fig. 71 represents a test-object from Otto Becker. The width of Snellen's lines corresponds with those forming his test-letters No. XX, and should be placed in a good light 20′ distant. The emmetropic eye sees all of the lines equally clear, black, and sharply defined. The abnormally astigmatic eye — any existing myopia or hypermetropia in the least deviating meridian being corrected — sees one line very black and sharply defined, while others are pale and indistinct.

As the accommodation for a specified distance, in high degrees of astigmatism, varies in different examinations, or even during different periods of the same examination, in order to obtain absolutely correct results, it is first necessary to paralyze the muscle of accommodation with atropia; in practice, however, this is sometimes dispensed with, as the determinations of the degrees of ametropia existing in different meridians may often be obtained with sufficient accuracy for practical purposes without it; the latter course, however, should not be recommended, unless the patient is so situated that he can undergo several examinations, and submit the prescribed neutralizing glasses to the test of experience.

Clinical Determination of Abnormal Astigmatism.

By means of Snellen's or Green's test-circles of radiating lines.— A patient presents himself, and states that he has always had defective vision; that he does not see objects distinctly. He is requested to read No. XX Snellen's test-letters, hanging on the wall at 20′ distant; this he is unable to do, but he makes out No. XXX; hence, the sharpness of his vision is $\frac{20}{XXX}$. Now place weak concave glasses before his eyes; if these make his sight worse, we conclude that he

Figure 65.

Figure 66.

Figure 67.

Figure 68.

Figure 69.

Figure 70.

is not myopic; then test for hypermetropia, by placing convex lenses before his eyes. If neither concave nor convex glasses improve his vision, we suspect that he has abnormal astigmatism, and to determine this, he is requested to look at Green's or Snellen's test-circle of radiating lines hanging on

Figure 71.

the wall 20′ distant. He sees some of the lines sharply defined and very black, while others are pale and indistinct; perhaps some appear separated by unequal distances. If it be the horizontal lines that are distinctly seen, we know that the vertical meridian is emmetropic or hypermetropic; to determine which, place before his eyes weak convex glasses; if these dim his vision of horizontal lines, we then conclude that the vertical meridian is emmetropic. In these tests of vision, each eye should be examined separately. We now desire to find the degree of ametropia existing in the horizontal meridian. To accomplish this, place successively several weak concave lenses before the eye, and endeavor to

make the vertical lines distinctly seen; if this cannot be done by negative lenses, then try convex ones; if, for illustration, a positive spherical glass of $\frac{1}{20}$, makes the vertical lines very black and distinctly seen, we conclude that he has hypermetropia in the horizontal meridian, and that its degree approximates $\frac{1}{20}$. We have now ascertained the refractive state of the eye in its maximum and minimum meridians of curvature. A cylindrical convex lens of 20″ focus is placed before the eye, with its axis corresponding to the vertical emmetropic meridian; instantly all of the lines are distinctly and uniformly seen; the errors of refraction are neutralized. He is now requested to read No. XX, which he does easily. His eye, with the aid of the glass, has become emmetropic. Small print is then given him, and if he be not presbyopic, he easily reads at 5″ or 6″ to 15″ or 18″ from the eye. If, in looking at the test-circle, none of the lines are distinct, convex or concave glasses are placed before the eye, until one is found which makes a line distinctly seen; the focal length of this glass represents either the actual or manifest grade of ametropia in the meridian perpendicular to the clearly seen line; the other principal meridian can be determined in the same manner, and the difference between the glasses represents the astigmatic variation.

Method of Strawbridge.

Dr. George Strawbridge, of Philadelphia, has devised a very excellent and convenient method for the determination of astigmatism. He describes it as follows: *

"I think it will be readily admitted that a more simple and convenient method for the determination of astigmatism is something very much to be wished for, but as yet not reached; and, with this end in view, I submit the following plan, based on an experiment described in 'Helmholtz's Optics,' page 107, to wit:

* Transactions of the American Ophthalmological Society, July, 1871.

"'If the light from a gas-lamp, or from the sky, be allowed to pass through a small round opening in a screen, such a light will appear, to an eye not exactly accommodated for it, as a star, with light radiation proceeding from it in various directions. Now, if a diaphragm is pushed slowly from the side so as to pass gradually in front of the eye, it will be observed that this "light figure" begins to be *shaded* on the *same* side *from which the diaphragm was moved*, if the object is *farther* removed than the *point* for which the eye is *accommodated*, but from the *opposite* side, if the object is *nearer* than the point for which the eye is accommodated.'

"The reason of this will be readily seen by examination of Fig. 72.

"Rays of light proceeding from point a, after passing through lens b, will unite at point C, and on the retina E E′ a sharp image of the object will be thrown. But, suppose the eye to be hypermetropic, and the retina to be at H H′, then, instead of a sharp image, circles of dispersion will be formed of a diameter represented by p q. If in this circle we particularize the two points, p q, which are met by the light proceeding from a, as a result, the individual, under these circumstances, will consider that the upper point p in the retina represents the image of an object situated in the field of vision below the real light-point a (as P in diagram), and the lower point q, of an object *above* the real light-point (as Q in diagram): following the rule that images on the retina are inverted, and a lower-situated object corresponds to a higher-situated image on the retina.

"Now, it will be readily understood that, by cutting off the rays of light as in the section S S′ by a diaphragm, if the eye is *hypermetropic*, the semicircle of light-dispersion, p p', on the retina H H′, will be intercepted; while, if the eye is *myopic*, the semicircle of light-dispersion, t t' on retina M M′, will be intercepted, and to the observer the effect will be, if hypermetropia exists, that the lower half of the light-circle at a will first vanish; while, if myopia exists, the upper half

of the light-circle will first disappear as a consequence of the position of the images on the retina.

"With these preliminary remarks, I proceed to describe the method of examination:

"In the centre of a Bristol-board, a round aperture of thirteen millimetres diameter is made, and at a distance from

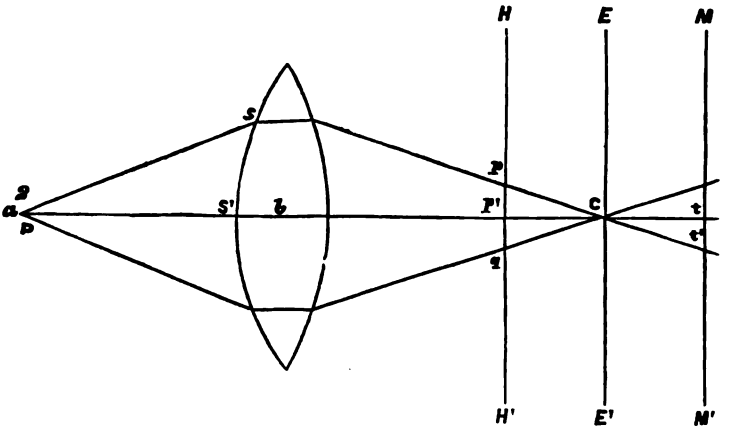

Figure 72.

a, Light-point in space; *b*, Refractive media of eyeball; C, Focus of lens *b*; E E′, Position of retina in emmetropic eye; H H′, Position of retina in hypermetropic eye; M M′, Position of retina in myopic eye.

this aperture of six centimetres, radiate bars are cut in the Bristol-board, having a length of nine centimetres, and a width of five millimetres, and forming an angle with each other of ten degrees. (See Fig. 73.) Over this figure white gauze paper is pasted, and a lamp, placed behind, illuminates it in its entire extent.

"The patient is placed at a distance of twenty feet from the figure, and requested to observe the round central opening, and to notice in what direction it is most elongated. This is readily determined by observing to which of the bars in the figure the light-prolongation most closely corresponds in its direction, and the result will be controlled, as to its

accuracy, by also finding which of the bars are most distinctly seen. For example, in a case of myopic astigmatism in the vertical meridian, it would be found that the light-elongation would be upward and downward, and at the same time the vertical bar would be most distinctly seen.

"By this procedure the *direction* of the meridian is discovered. The next step is to determine the *refraction* of the *meridian*.

"To this end, a diaphragm is advanced in the direction of the greatest elongation of the round light (suppose it to be vertical, and that the diaphragm moves from above downward), and the patient is requested to notice whether the upper half of the round light first disappears or the lower half, as the diaphragm moves downward; if the upper half is first gone, the meridian is shown to be so curved as to cause a *myopia* to *exist*: while, if the lower half of the round light is the first to disappear, we conclude that a *hypermetropia* exists.

"If the entire round light is found to disappear at once, it may be concluded that very little astigmatism exists.

"The direction of the meridians being now known, as well as their refraction, whether normal or so curved as to cause a myopia or hypermetropia, the next step would be to determine exactly the *amount* of *abnormality*.

"To this end we proceed with spherical glasses, determining the exact one necessary to see distinctly the proper bar, as in the method laid down by Snellen.

"Advantages of this method —

"1. Simplicity. The usual methods are, as a rule, so complicated that the patient often becomes confused in the examination, and an error can easily result; but to this new procedure no such objection can be made.

"2. Accuracy, which results from the extreme delicacy of the test formed by the illuminated bar.

"3. The great saving of time, arising from the fact that the mode of examination can be conducted so much more quickly than by the ordinary methods.

"4. This method allows of examination being made entirely independent of daylight, and so obviating any inconvenience arising from defective illumination found in cloudy weather, etc.

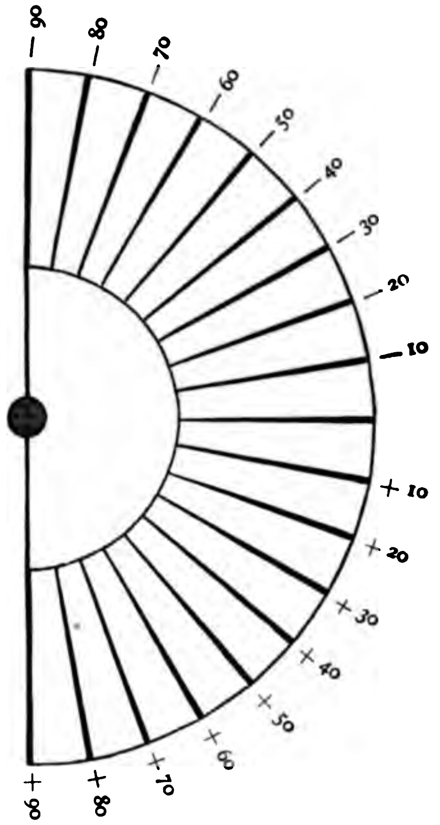

Figure 73.

"In Fig. 73, the black circle and broad lines represent the central round aperture and bars, which are illuminated by a light placed behind."

The method of Strawbridge gives by far the most accurate results, as it does not depend on the judgment of the patient for determining the acuteness of his perceptions of

the different degrees of distinctness with which the test-objects are seen, which, after lengthened examinations by ordinary methods, is liable to become more or less confused.

Figure 74.

Method of Risley.

Recently, while on a visit to Philadelphia, we saw an ingenious instrument for the detection and measurement of astigmatism, devised by Dr. S. D. Risley, which he calls a *Visuometer.* He claims for it, that in its present form it is new, and that with its aid he can arrive at more accurate determinations of the defects of refraction, with much less expenditure of time, and with less fatigue both to himself and to the patient.

As seen in Fig. 74, his instrument consists of a stand, which clamps firmly to the table. To the top of the stand is fixed a pair of semicircles, with their concavity upward, for the reception of trial glasses, stenopæic slit, etc. They are graduated to correspond with the Nachet trial frames. In front of the holders is a triangular horizontal bar, 20″ long, graduated in fractions of an inch. Upon this bar is adjusted a freely-moving carrier, designed to bear a series of cards containing the test-types of Snellen and Jaeger, and a large number of test-figures for astigmatism, among which is the system of radiating lines of Dr. Green, of St. Louis. The whole set is intended for use at 12″ instead of 20′. Many of the tests are cut in thin brass disks, and are to be used over an illuminated background, which is furnished by different-colored plates of ground glass. There is a plate fitting the carrier, with central opening designed to receive these disks, and to permit their free rotation over a graduated scale corresponding to that upon the holders. One of the most valuable of this series of test-objects is a wire optometer, consisting of a brass rim with two groups, each containing five wires, stretched one millimetre apart, the two groups crossing the centre at right angles.

His determinations are all made at an artificial far point — 10″ or 12″ inches. He regards the paralysis of the accommodation by atropia necessary in every case where a careful measurement of the anomaly is desired, remarking that "*the accommodation stands as a never-varying unknown quantity to vitiate results.*"

He begins by placing + $\frac{1}{12}$ in the holders before the eye, and Jr. No. 1 or Sn. $1\frac{1}{2}$ at 12″. The stenopæic slit is then dropped into a second groove in the holders, and by means of its milled edge rotated before the eye until the direction of most distinct vision is found. The condition of refraction in this meridian, and the one perpendicular to it, is tested by placing the trial glasses in front of the slit in a third groove in the holders. The refraction of the two meridians, as well as

their direction, is thus rapidly ascertained. The result is verified by removing the slit, and placing in its stead a disk with two perforations four millimetres apart (Thomson's modification of the experiment of Scheiner), the holes being placed in the direction of the meridians of greatest and least curvature, already learned by the stenopæic slit. The letters at 12″ are now removed, and a brass disk with a central hole two millimetres in diameter placed in its stead, which affords a bright point of light. The ametropia will be revealed by this being doubled, when viewed through the small disk placed near the eye. The glass which fuses the double images is the correcting glass for any given meridian; their difference the degree of astigmatism. This test is further employed by moving the point of light until the distance at which double images are fused is found, when the difference between that and 12″ would be the degree of ametropia. Several other means are at hand of arriving at the same result, or proving further results already attained,—*e.g.* $+ \frac{1}{12}$ being still before the eye, the wire optometer, or either of the numerous test-figures, is placed at a point too remote for distinct vision, and carefully moved toward the eye. The patient is requested to note which diameter of the figures, or set of lines or wires, as the case may be, first come into view. If the case be one of hypermetropia and astigmatism, this will be farther than 12″ from the eye; if myopia, it will be nearer than 12″. This point being noted, the figure is now moved up until the lines perpendicular to the first are clearly seen, when, by a very simple calculation, the degree of ametropia and astigmatism is known; or the test-figure being placed at 12″ by means of trial glasses, the refraction of the different meridians is ascertained. The selected combination is then placed in the holders, Jr. No. 1 placed at 12″, and required to be read; if this be readily done, $+ \frac{1}{12}$ being removed, he is expected to have $v = \frac{20}{\text{xx}}$. There is also an opportunity afforded for the employment of the color tests

for ametropia. Experience will probably prove that the determination of the degree of ametropia from an artificial far point is not as reliable as that derived from test-objects placed twenty feet distant. Dr. Risley's instrument is a very convenient one for applying many of the tests in general use.

A valuable addition to the visuometer is an adjustable *perimeter*, which can be readily removed when not in use. It is represented in the figure as adjusted for use.

Method of Dr. Thompson.

Dr. William Thompson, of Philadelphia, has devised a very simple and convenient instrument for the determination of ametropia, and which is particularly useful in astigmatism for measuring the errors of refraction existing in the principal meridians. His tests are exceedingly delicate, and the results obtained are remarkably accurate. A description of his instrument, and the manner of using it, are given in his own language, as written for the "Surgery" of Dr. Gross.

Dr. Thompson's optometer "consists of four screens of thin brass perforated as follows:

"No. 1. One hole, 1 millimetre diameter.
" 2. Nine holes, ½ " "
" 3. Two holes, 3 millimetres apart, ½ millimetre diameter.
" 4. " " 4 " " ½ " "

"The patient, during the investigation, should be placed in a darkened room, at not less than sixteen feet from a point of light, which may be a candle, or gas-light turned down low. He should look at the light through No. 1, and, at the same time, move the screen quickly before his eye. If the length of the axis of the eye be normal, and the refraction hence emmetropic, the point of light will remain stationary; should the eye be ametropic, the eye will dance with each movement of the screen. With No. 2, the light will appear single to an emmetropic eye, multiplied to one ametropic. With No. 3, the light which enters the two perforations will

appear to the observer, when placed near to his eye, to come from two large circles, at the screen, which overlap each other at their inner borders. In this overlapping space only will the test light appear double to an ametropic eye; and care must be exercised that the patient uses both apertures, and not one only; and that his attention is fixed upon the 'overlapping space.' This screen is provided with a piece of ruby glass, which can, at pleasure, be pushed over one perforation, and thus color the light which enters it red. Let it be supposed that a person with myopia is under examination, and that he sees the light point in the overlapping space as two lights. On pushing the red glass over the hole towards the right side, the light on the right appears crimson, and thus indicates that the axis of the eye is too long. Should the axis be too short, and hypermetropia be present, the left-hand light would become colored, when the right-hand hole was covered with red glass.

"With No. 4, we are able to determine, without test glasses, the degrees of optical defects, by estimating the apparent distance apart of the two lights as they appear to an ametropic eye. There is a measured and fixed quantity, four millimetres, in the screen, and the patient should be placed at a fixed distance, five metres, from the light, when the degree of defect, and the convex or concave glass proper for its correction, can be ascertained by the measurement of the distance between the two lights. To render this of service clinically, these quantities have been reduced to the English measure, and a table has been made, as will be seen below, to indicate at a glance the optical defect, which accompanies each separation, in inches, of the two lights.

"The patient being placed sixteen feet from a small point of light, when it appears double, approach to it a second light, held in the surgeon's hand, until of the four points which the patient then perceives, the right hand one of the fixed, and the left hand one of the moving, lights are superimposed, and the patient sees but three; then ascertain with

an ordinary measure the distance between the two lights, and its corresponding optical defect can be read off from the table.

"A blackened tin disk, ten inches in diameter, having white lines one inch apart painted on its face, attached to a spring candlestick by a pivot, having in its centre an opening $\frac{1}{4}$ inch in diameter, through which the light of a candle may be transmitted, affords a very useful instrument. Let the patient regard this small point of light, and when he sees it double, he can at the same time determine the number of white lines between the lights, and hence the distance, since the lines are one inch apart. By rotating the disk and changing the position of the screen, any meridians of the eye can be examined in cases of astigmatism.

"By examining the table, it will be observed that a separation of one inch indicates an ametropia of $\frac{1}{32}$, and may be corrected by a + or — $\frac{1}{32}$, which will fuse the two lights into one.

Distances of Light Apart.		Degree of Ametropia.	Distances of Light Apart.		Degree of Ametropia.
$\frac{1}{2}$ inch.	=	$\frac{1}{64}$	5 inch.	=	$\frac{1}{6.5}$
1 "	=	$\frac{1}{32}$	6 "	=	$\frac{1}{5.3}$
$1\frac{1}{2}$ "	=	$\frac{1}{20}$	7 "	=	$\frac{1}{4.6}$
2 "	=	$\frac{1}{16}$	8 "	=	$\frac{1}{4}$
3 "	=	$\frac{1}{10}$	9 "	=	$\frac{1}{3.6}$
4 "	=	$\frac{1}{8}$	10 "	=	$\frac{1}{3.2}$

Methods of Young and Graefe.

Thomas Young proved the existence of astigmatism in his own eyes, by means of fine wires; he found that he had to vary their distances from the eye, that they might be distinctly seen in the different meridians. Graefe also made use of the "Wire Optometer" to determine astigmatism and its degree. His instrument consisted of fine wires stretched across a frame, having a tape-measure attached, with which

to note the distance of the wires from the eye, in its adjustment for the different meridians.

Method of the Stenopæic Slit.

Another method of ascertaining the existence of astigmatism is this. While looking at letters or other objects, a stenopæic instrument is placed before the eye,— that is, a narrow slit half a line to a line in width cut in a blackened card or metal plate,— one that has a slide is preferable, so that the slit may be narrowed or widened at pleasure, — and rotated in a plane perpendicular to the visual line; if there be astigmatism, some position of the slit will be found in which vision is improved; when the slit is turned perpendicular to this, the greatest indistinctness will result. The positions causing the maximum and minimum degrees of distinctness determine the situations of the meridians having the maximum and minimum radii of curvature. By means of spherical glasses placed behind the instrument, the degree of ametropia existing in the different meridians can easily be ascertained.

Method by the Phenomena of Dispersion.

Helmholtz has shown that high degrees of astigmatism can be detected by means of the phenomena of dispersion, if colors having the greatest difference in the degrees of refrangibility be employed. Dark violet-colored glass excludes the middle rays of the solar spectrum, and permits the passage of the red and violet rays. Dark-blue cobalt glass permits the red and blue rays to pass through it, while it excludes the others. Now, if sunlight falls on a dark screen, in which there is a round or square hole which permits the light to pass, a myopic person with the violet glass before his eyes will see the edges of the hole in the screen blue, while its middle will be violet. If he be hypermetropic, the centre will be blue, and the border red. If a candle be em-

ployed, the myopic eye, looking through dark cobalt glass, sees the edges of the flame blue, and its central part red; on the contrary, if the eye be hypermetropic, the position of the colors is exactly reversed. In high degrees of astigmatism, if the vertical edges of the candle are red, and the superior and inferior parts blue, or *vice versâ*, it indicates myopia in one of the principal meridians, and hypermetropia in the other. If, on looking through the colored glass, the point of light be drawn out into a line, the extremities are of one color and its middle another. The explanation of these phenomena is very simple, and has been given on page 43.

Various complicated instruments have been devised and constructed to determine the degrees of astigmatism and the positions of the principal meridians. Among these the "astigmatic lens of Stokes" has taken pre-eminence. It consists of a convex and a concave cylindrical lens placed in rings which rotate on each other. By arranging the axes of the lenses parallel, one exactly neutralizes the other. The instrument is now placed before the eye, and one ring rotated on the other until a point is found where the vision becomes distinct. Figures are placed on the edges of the rings, by which the degree of ametropia can be at once determined, and the position of the glasses indicates the situation of the principal meridians. Donders states — and the same remark is applicable to most other complicated instruments devised for a similar purpose — "that the method is not very applicable to practice." The asymmetry of the different meridians may be measured by "ophthalmoscopic optometry." It is only necessary to find a glass which makes, in the erect image, the retinal vessels in any particular meridian distinctly seen; the focal length of the glass, increased or diminished by its distance from the eye, as the required lens may be positive or negative, indicates the degree of asymmetry in the meridian perpendicular to the directions of the vessels. Drs. Knapp and Schweiger were the first who pointed out the variable forms

of the optic disk, as seen with the ophthalmoscope, as an indication of the existence of abnormal astigmatism; the direction of its elongation determining one of the principal meridians.

In abnormal astigmatism the greatest disturbances to vision take place when the pupil is widely dilated; the smallest when it is most contracted; hence, subjective examinations are usually made when the size of the pupil is a medium between the two extremes, particularly when it is desired to verify by experience the correctness of the results obtained with paralyzed accommodation.

Forms of Astigmatism.

The following are the different forms of astigmatism, described and named by Donders, according to the symmetrical or asymmetrical formation of one or both of the principal meridians.

1. *a*, Simple myopic astigmatism.
   b, Compound " "
2. *a*, Simple hypermetropic "
   b, Compound " "
3. Mixed astigmatism.

Simple myopic astigmatism is where one of the principal meridians is emmetropic; the other, myopic. If, for illustration, there be E. in the horizontal meridian and myopia of $\frac{1}{10}$ in the vertical, the astigmatic deviation is found, and is expressed as follows: Am. $= \frac{1}{10} - \frac{1}{\infty} = \frac{1}{10}$.

Compound myopic astigmatism is that condition in which myopia exists in all of the meridians, but to a greater degree in some than in others. For illustration, let there be myopia in the horizontal meridian $= \frac{1}{16}$, and in the vertical $= \frac{1}{8}$, then $\frac{1}{8} - \frac{1}{16} = \frac{1}{16}$. M. $= \frac{1}{16}$ exists in horizontal meridian and Am. $= \frac{1}{16}$ exists in the vertical meridian, expressed M. $\frac{1}{16}$ + Am. $\frac{1}{16}$.

Simple hypermetropic astigmatism is where E. exists in one of the principal meridians and H. in the other. For illustration, let there be in the vertical meridian E., and in the horizontal meridian H. $= \frac{1}{12}$, expressed Ah. $= \frac{1}{12} - \frac{1}{\infty} = \frac{1}{12}$.

Compound hypermetropic astigmatism is where hypermetropia exists in all the meridians, but to a higher degree in some than in others. If in the horizontal meridian there be H. $= \frac{1}{20}$, and in the vertical H. $= \frac{1}{10}$, then Ah. $= \frac{1}{10} - \frac{1}{20} = \frac{1}{20}$, which indicates the astigmatic deviation. This condition of the eye is expressed as follows, H. $\frac{1}{20}$ + Ah. $\frac{1}{20}$.

Mixed astigmatism indicates that M. exists in one of the principal meridians and H. in the other.

If the M. predominates, it is expressed Amh.

" " H. " " " " Ahm. For illustration, M. $= \frac{1}{12}$ in the *v* meridian, H. $= \frac{1}{24}$ in the *h* meridian. Then it is expressed Amh. = M. $\frac{1}{12}$ + H. $\frac{1}{24} = \frac{1}{8}$.

If, on the contrary, H. $= \frac{1}{12}$ in the *h* meridian,

M. $= \frac{1}{24}$ " " *v* " .

Then it is expressed, Ahm. = H. $\frac{1}{24}$ + M. $\frac{1}{12} = \frac{1}{8}$.

As to the influence of asymmetry of the crystalline lens, Donders states that investigations "*have supplied me with proof that, with a high degree of asymmetry of the cornea, asymmetry of the crystalline lens exists, acting in such a direction, that the astigmatism for the whole eye is nearly always less than that proceeding from the cornea.*" Abnormal astigmatism is usually congenital, and often hereditary. When one of the parents is affected, often several of the children are likewise affected, each one having a similar form of asymmetry. Hypermetropic astigmatism is much more common than the myopic form. Both eyes are usually similarly affected, although one may be astigmatic and the other emmetropic. When the asymmetry is confined to a single eye, there is usually asymmetry of the bones forming that orbit, particularly in the hyperme-

tropic form. The former is more frequently accompanied by symptoms of accommodative asthenopia. In the higher degrees of abnormal regular astigmatism, the disturbance of vision is very marked; the retinal images are distorted and the impressions projected outward, causing objects to appear of unnatural shapes. Parts of them are sharply seen, while other parts are indistinct. There is a continual effort made by the accommodation to find some point of adjustment that renders vision more clear; but it is difficult to determine this point accurately, as there is wanting that definite sensation which determines the exact required amount of innervation of the ciliary muscles. They act in a hesitating, unsteady manner, causing rapid changes in the accommodation that produce alternating images. "It is now easy to understand how, in the endeavor to guess at the form of objects, from the alternating images which appear in the agitation of accommodation, psychical fatigue is soon created, with which, under some circumstances, as the result of the excessive tension of the accommodation, phenomena of asthenopia are combined. It is therefore no wonder that astigmatic persons should feel so exceedingly pleased at the correction of their anomaly, and should manifest their pleasure in a more lively manner than ordinary ametropic individuals." (*Donders.*)

Treatment of Abnormal Regular Astigmatism by the Adaptation of Cylindrical Lenses.

The remedy for abnormal astigmatism consists in neutralizing the errors of refraction of each particular meridian by means of cylindrical or spherico-cylindrical lenses. Cylindrical lenses are longitudinal sections of cylinders. They are convex or concave, according as they are sections of the outer or inner surfaces of a hollow cylinder. They may be either plano-convex or plano-concave, bi-convex or bi-concave, or they may have the forms of the positive or negative meniscus. Spherico-cylindrical glasses have one surface ground spherical and the other cylindrical. In a simple cylin-

drical lens, rays of light falling on the plane of the meridian passing through its axis, do not change their direction; in this meridian the lens is simply a plate of glass with parallel surfaces. All the other meridians refract the light,—those nearest the axis the least, but with gradually increasing power as they approach the meridian perpendicular to the axis, in which position the maximum degree of refraction is attained. Precisely the same gradations of refractive power take place in the eye, between the normal, or the least deviating meridian, and the one of the greatest astigmatic deviation; consequently, if in simple astigmatism a cylindrical glass of suitable strength, positive or negative, as the case may be, be placed before the eye with its axis corresponding to the emmetropic meridian, the errors of refraction of each deviating meridian will be neutralized and the *v.* should then $= 1$. In case of compound myopic or hypermetropic astigmatism, the ametropia in the least deviating meridian should be first neutralized by a spherical lens, and the astigmatic deviation by a cylindrical lens, with its axis in the plane of the meridian made emmetropic by the spherical glass. Mixed astigmatism is corrected either by a spherico-cylindrical lens of required strength, or by a positive and a negative cylindrical lens placed in apposition with axes perpendicular to each other. We give the proper strength of the neutralizing cylindrical glass, and of the position of its axis, in a supposed case of each of the different forms of abnormal regular astigmatism. The distance of the glass from the eye is not taken into consideration in these examples.

Simple myopic astigmatism.

If there be in *h* meridian E.
" " " *v* " M. $= \frac{1}{20}$,

then Am. $= \frac{1}{20}$, and the proper lens to correct it would be a cylindrical concave of 20″ focus, axis horizontal.

Compound myopic astigmatism.

If there be in the principal *h* meridian $M. = \frac{1}{20}$,

" " " " " *v* " $M. = \frac{1}{10}$,

then there is a myopia of $\frac{1}{20}$ with an astigmatic deviation of $\frac{1}{20}$, expressed $M. = \frac{1}{20} + Am. \frac{1}{20}$. This is corrected by a lens one surface spherical $-\frac{1}{20}$, and the other cylindrical $-\frac{1}{20}$, written $-\frac{1}{20}$ S ⊂⊃ $-\frac{1}{20}$ C, axis horizontal.

Simple hypermetropic astigmatism.

If there be in the *v* principal meridian E.,

" " " *h* " " $H. = \frac{1}{12}$,

then $Ah. = \frac{1}{12}$. This would be corrected by $+\frac{1}{12}$, cylindrical lens axis vertical.

Compound hypermetropic astigmatism.

In the principal *v* meridian let there be $H. = \frac{1}{18}$,

" " " *h* " " " $H. = \frac{1}{12}$.

There is hypermetropia in all of the meridians, but not of uniform degree. The astigmatic deviation is $\frac{1}{12} - \frac{1}{18} = \frac{1}{36}$, expressed $H. \frac{1}{18} + Ah. \frac{1}{36}$. This is corrected by a spherico-cylindrical lens, one surface ground spherical $+\frac{1}{18}$, the other cylindrical $+\frac{1}{36}$, written $+\frac{1}{18}$ S ⊂⊃ $+\frac{1}{36}$ C, axis vertical.

Mixed astigmatism.

Here, as the hypermetropia, in reference to the far point, has a negative value as compared to the myopia, the astigmatic deviation is found by adding the refractive state.

Predominant myopia.

Let in the *v* principal meridian $M. = \frac{1}{8}$,

" " *h* " " " $H. = \frac{1}{16}$,

then Amh. $= \frac{1}{8} + \frac{1}{16} = \frac{1}{5\frac{1}{3}}$, neutralized by a bi-cylindrical lens, one surface concave, the other convex, axes perpendicular to each other, written $+ \frac{1}{16}$ C $\ulcorner$ $\frac{1}{8}$ C, axis of concave surface horizontal, the convex will then be vertical.

Predominant hypermetropia.

Let in the *v* principal meridian M. $= \frac{1}{12}$,

" " *h* " " " H. $= \frac{1}{6}$,

then Ahm. $= \frac{1}{12} + \frac{1}{6} = \frac{1}{4}$, neutralized with a bi-cylindrical glass, expressed $+ \frac{1}{6}$ C $\ulcorner$ $- \frac{1}{12}$ C, axis of convex surface vertical; of the concave surface horizontal. Mixed astigmatism may also be neutralized by spherico-cylindrical glasses. In the first case above given, the required glass would be $\frac{1}{16}$ S $\bigcirc$ $- \frac{1}{5\frac{1}{3}}$ C, axis horizontal. In the second instance, the correcting glass would be $- \frac{1}{12}$ S $\bigcirc$ $+ \frac{1}{4}$ C, axis vertical. On account of the prismatic deviations and lateral distortion of objects caused by the strongly curved surfaces of this form of lens, required in high degrees of mixed astigmatism, the bi-cylindrical glass is preferable, which should be made from crown-glass, owing to its feebler dispersive power. It is not always desirable, in high grades of astigmatism, to bring the far point to an infinite distance, on account of the very strongly curved cylindrical surfaces required to produce this result, as these would cause more or less spherical and chromatic aberrations; the obliquely falling rays would produce distorted retinal images of objects which would be excessively annoying, besides the disturbance of the innate conditions of relative associations that lead to asthenopia. "This disturbance is very decided even in simple myopia and hypermetropia of a high grade, but is even greater where there is accompanying astigmatism, since here the necessity for a greater visual angle for sharp vision increases considerably the deviation of the natural states of association." (*Stellwag.*)

In certain cases it is only desirable to bring the far point to a distance suited for special occupations, as, for illustration, reading music, etc.; here *r* should be at about 24″ from the eyes. It is necessary, to accomplish this result, to bring both chief meridians to the same adjustment, for example $\frac{1}{24}$, instead of rendering the eye emmetropic. This is done by deducting the desired adjustment from the power of the spherical surface of the correcting lens, necessary to remove *r* to an infinite distance. For illustration, suppose the lens required to render the eye emmetropic be $-\frac{1}{12}$ S $\subset -\frac{1}{12}$ C, then to partially neutralize the ametropia, and enable the music to be at *r*, that is, 24″ from the eye, $\frac{1}{24}$ must be deducted from the strength of the spherical surface of the lens, —thus $\frac{1}{12}-\frac{1}{24}=\frac{1}{24}$. The proper glass then would be — $\frac{1}{24}$ S $\subset -\frac{1}{12}$ C.

With the latter glass, objects should be distinctly seen 24″ from the eye. Other distances are obtained in a similar manner. Cylindrical glasses, while they greatly improve the vision of the astigmatic eye, can never render it perfect; the neutralization is never complete; if the cylindrical lens could be made an integral part of the dioptric apparatus, this might be accomplished; but it is necessary to place the glasses at a distance from the eyes, and to have the errors of refraction corrected, the planes of light passing through each meridian must fall perpendicularly on the meridian of the curvature of the surface of the lens, which corrects a deviating meridian of the cornea, lying in the same plane. As the lens, after being suitably adjusted to neutralize the errors of refraction in each plane of light falling perpendicularly on a meridian of the lens surface, and passing through a corresponding meridian of the eye, cannot change its position, it follows that every movement of the latter displaces this accurate adjustment, so that planes of light, passing through each meridian of the glass, no longer correspond to the meridian

of the eye, the refraction of which it should correct. This constant variation in the positions of the eye in reference to the fixed glass does not, in low degrees of astigmatism, seriously interfere with the sharpness of vision; but in the higher grades it becomes the source of great disturbance, for which there is no remedy.

Irregular Astigmatism.

This form of astigmatism is also divided into *normal* and *abnormal.* The former has its origin in the peculiar construction of the lens; the latter may be connected with irregularities either of the cornea or of the lens.

Normal Irregular Astigmatism. — In a child recently born, the anterior surface of the crystalline lens has three lines radiating from its centre, dividing the surface into three triangles; along the course of each of these lines, filaments arise and pass towards the equator over which they bend; those filaments having their origin near the anterior pole terminate in flattened filaments just behind the equator, while those arising farther from the anterior pole terminate proportionally nearer the posterior pole. "Thus, a number of filaments form one triangle in the anterior half, while in the posterior half they form two triangles of nearly equal size, which are only the halves of two other similar triangles on the posterior surface. In the newly born, on the anterior, as well as on the posterior, of each layer, there are almost always three such triangles. They are called vortices, and form a stellate figure with three rays. With advancing age and continued apposition of new filaments, these vortices multiply, and the rays of the stellate figure increase. Finally, a second set of vortices is developed, which come to a point at some distance from the pole." (*Stellwag.*) It is easily seen that each of these sectors—and even the filaments which comprise them — have irregularly curved surfaces, and that these are spread over the curved surfaces of the lens. The central portions of the sectors and of the filaments act as so many minute, weak convex spherical or cylindrical lenses

lying on the surface of the lens, while the depressions which exist at the juxtaposition of the sectors and filaments act as so many exceeding minute and feeble concave lenses. If a small round ink dot be made on a piece of white paper, and the eye be accurately adjusted for the black spot, it will appear round and sharply defined; if now it be brought slightly within the near point, each of the smaller convex surfaces will unite the rays from the dot falling on it, at different points on or near the retina, so that, instead of one black dot, numbers of pale or grayish ones are seen, generally arranged in a circular form, although their numbers and positions vary with different persons and in the two eyes of the same person. When the dot is carried a little beyond the far point, its images again become broken into numbers of indistinct ones; but here it is the little concave surfaces which make the separate images, because their foci are farther back than the focus of the lens. In order that the object may be more easily moved nearer or beyond the point of distinct vision, a convex lens of $\frac{1}{5}$ or $\frac{1}{6}$ should be placed before the eye. Similar effects can be produced by placing a minute granule of white lead, obtained from scraping a visiting-card, on a piece of black velvet; but here each spot appears radiatingly elongated; the phenomena of dispersion comes into play, causing alternate red and blue centres and borders, according as the object is situated nearer or farther than the point of distinct vision. If the granule be exceedingly minute, the elongated lines give way to "slender rays, which, when the granule lies nearer than the distance of distinctness, do not run together in the middle, and which, on the contrary, have a white spot in the centre, when the object is beyond the distance of distinct vision." (*Donders.*) A point of bright light, when just outside the limits of distinct vision, divides into a number of bright rays, each central point corresponding with one of the pale dots, when the latter was experimented with. An imperfectly defined image of a minute object is formed by each sector of which the lens is composed, and when the accommodation cannot be quite adjusted for the multiple images, it

is likely that the lens filaments, which are a little flattened and proceed from the radiating lines passing toward the equator, act as numerous minute cylindrical lenses; that is, they unite homocentric rays falling on them in lines. A presbyopic person, when he attempts to read print, particularly by artificial light, for which his glasses are a little too weak for accurate adjustment, often sees the page mottled, as it were,—some spots in which the print is very black, others in which it is very pale or grayish. The causes of irregular astigmatism have their origin undoubtedly in the peculiar structure of the crystalline lens; the irregular sectors of its anterior surface, and the radiating figures from which the fibres proceed, can be plainly seen by an observer in oblique illumination, and by a person himself in entoptic examinations. The sectors are irregularly curved, giving rise to distorted or astigmatic images. That normal irregular astigmatism causes monocular polyopia, etc., which arise from inequalities in the structure of the lens, is proved by the fact that when the crystalline is removed these disappear. They are seldom so sufficiently marked in persons having a good range of accommodation, particularly in binocular vision, as to interfere with the sharpness of vision. In diminished range of accommodation, when the object is easily moved out of the region of distinct vision, the phenomena often appear. *Abnormal irregular astigmatism* may be caused either by irregularities of the cornea, or of the lens, or by the misplacement of the latter giving it an oblique position. The regularity of the surface of the cornea, or of single meridians, may be destroyed either by disease or by injuries. Among the diseases that change the regular convexity of the anterior surface of the eye, and which lead to a high degree of irregular astigmatism, may be mentioned *conical cornea.* This condition is often overlooked, and what is really an error of refraction is too frequently attributed to and treated for amblyopia. Graefe, and more recently Mr. Bader, relieved such cases and restored vision, by shaving off the apex of the cornea and producing a cicatrix, the contraction of which restored the cornea to

its natural shape. When this happy result does not take place, it is recommended to excise a portion of the iris at some place where there is the least change in the form of the cornea, so that light passing through the new opening may be less disturbed by irregular refractions. Inflammation of the cornea, giving rise to softening, and consequently extension of particular parts, sometimes leads to asymmetry of its curvature. Cicatrices from ulcers, by contraction, often destroy the normal form of the cornea; also, cicatrices from injuries and wounds, particularly flap operations for extraction of cataracts, when union takes place by granulation or portions of the iris are healed in the wound, producing distortion of the pupil, so that light passes through a part of the flap which has lost its normal curvature. This condition can usually be corrected by a cylindrical glass, or by giving a spherical glass placed in an oblique position. Ectopia, or a slight displacement of the lens within the ciliary processes, without detachment, is not unfrequently the cause of a high degree of irregular astigmatism. The displacement usually takes place upwards and inwards, the visual line passing through the lens near its border. Rays of light are thus acted on the same as by a prism with curved surfaces; frequently giving colored borders to objects, which are always more or less distorted. Ectopia, according to Stellwag, "is always congenital, often hereditary, and frequently accompanied by a decided myopic formation of the eye." Opaque spots on the capsules, or opacities of certain parts of the crystalline lens, also cause irregular distortions of retinal images. Irregular astigmatism cannot be entirely corrected. Cylindrical or stenopæic glasses may partially do so, but vision can seldom be made to come up to the normal standard. Stenopæic slits or glasses are made to direct the light to certain points where the rays are the least abnormally refracted, and to exclude it from those parts which produce the greatest disturbances to vision; the stenopæic apparatus, combined with the cylindrical lens, may often be of service in improving vision.

DIFFERENCE IN REFRACTION OF THE TWO EYES.

There generally exists a great similarity between the two eyes, any difference being so slight that it requires delicate tests to determine it. It is the popular belief that the acuteness of vision of the right is greater than of the left eye. This is an error. The acuteness of sensibility of the two eyes is generally almost the same, particularly when either is used singly, but in binocular vision the sensorium gives preference to the perception of images formed in the right eye. This will be manifest to most persons with eyes nearly alike, if an attempt be made to place the finger in the line of vision when both eyes are directed to an object. It will generally be found that the finger obstructs the visual line of the right eye. In looking at an object situated in front of a back-ground, while the attention is not particularly directed to the latter, if a card be placed before the left eye, the disappearance of that portion of the back-ground alone visible to the left eye, will scarcely be noticed, while, if the card be placed before the right, the disappearance of that part of the back-ground belonging to this eye will sooner attract attention. The perfection with which images are fused in the stereoscope furnishes an excellent means of determining the degree of inequality of refraction existing between the two eyes. If there be much difference, perfect fusion of the two images cannot take place. Where monocular vision is required, as in sighting artillery, fire-arms, determining straight lines and rectilinear surfaces, in the use of the microscope, telescope, etc., preference is usually given to the right eye. But while, as above stated, the two eyes are generally very nearly alike, cases are frequently met with in which they differ more or less widely. One eye may be emmetropic, the other ame-

tropic, or both may be ametropic, but of different degrees. In general, the same form of ametropia exists in both eyes, but of a higher degree in one than in the other; or, in rare cases, myopia is found in one eye and hypermetropia in the other. There may be considerable difference in the refraction of the two eyes, and yet binocular vision be tolerably acute. In such cases sharp vision only exists in the more acutely-seeing eye, while the imperfect image formed in the other assists in the perception of parts of the objects at a distance from the point of fixation. Persons having unequal eyes are often unaware of it themselves, and only find it out by accident or experiment; they have been exercising them in that condition from childhood, and having had no experience in seeing with equal eyes, regard their vision as perfect. In neutralizing the errors of refraction in eyes having different degrees of ametropia, it becomes a question, What is the proper glass to select for each eye respectively in each particular case? When one eye is emmetropic and the other ametropic, a correcting glass for the latter is not required. When both are ametropic, it is generally proper to neutralize the ametropia existing in the most acutely-seeing eye, and give a similar glass for the other. This arrangement does not change the conditions of associations between accommodation and convergence, to which the eyes have by long use become accustomed, nor change the relative sizes of the two images. If, however, the difference in the errors of refraction in the two eyes does not exceed $\frac{1}{48}$ or $\frac{1}{60}$, there can be no objection to prescribing glasses having a corresponding difference in focal lengths. The magnitude of the images is so nearly alike, that they may be fused into the perception of one of intermediate size; but when these limits are much exceeded, the rule above given should be adhered to, for here, when glasses are prescribed which render each eye emmetropic, the positions of the nodal points are so changed that there is such a difference in the size of the retinal images that they cannot be made to fuse or cover each other, and double vision

results, to avoid which there is a tendency to a deviation of one eye from its natural position; or, if this does not occur, the accustomed conditions of associations between convergence and accommodation are so disturbed as to produce nervous and vascular irritation.

The rule given above is so often violated, that we quote from Donders, whose opinions carry with them the highest weight of authority. He says: "Where binocular vision is present, at any distance, the point is to maintain this, and if possible to render it capable of extension over a greater region. In the choice of glasses, we start from the more acutely-seeing eye, to which the other must remain subordinate. The question then remains, what glass the other eye requires. At first view we might suppose that for this latter we should have simply to choose the glass which brings the farthest point to the same distance at which it lies for the first eye. This is, in fact, the opinion of laymen. 'My eyes differ; consequently, I need different glasses,' — such is the ordinary reasoning. It is so evident, so palpable, and apparently so logical, that we cannot be surprised at it,— the less so, as the so-called 'opticians' are quite prepared to put two different glasses in the same frame. It is, however, far from being the case, that we should keep to this rule."

APPENDIX.

Instructions for the Adaptation of Spectacles.

WHENEVER practicable, persons needing spectacles should have the errors of refraction of their eyes accurately determined by an ophthalmic surgeon, and obtain from him a prescription for the proper neutralizing glasses, which the optician should fill strictly according to instructions given him; the relation of the latter to the former should be the same as that of the apothecary to the physician; but, owing to the great extent of our country, and the sparse population of large districts, embracing many of the smaller towns and cities, where no competent ophthalmic surgeon resides, it becomes necessary for persons needing spectacles to select them themselves. Heretofore they have chosen them by empirical methods, either unassisted or by instructions from spectacle-dealers who are as ignorant of the subject as themselves. The result has been that a large majority of persons wearing spectacles have injured their vision by the use of glasses unsuited to their eyes; nor does this appear at all strange when we bear in mind that they have no fixed rules to govern them in their choice. It is for this class of persons, so situated that they cannot conveniently obtain competent professional advice, that the Appendix is added to this work, in order to enable them to apply scientific principles in making choice of the proper glasses to neutralize their errors of refraction and supply deficiencies of accom-

modation. When a person has defects of vision which he thinks may be relieved by spectacles, the first step for him to take, is to ascertain the acuteness of his sight for distant objects. To accomplish this, he should turn to the end of this book, where he will find a folded sheet containing selections from the TEST-TYPES OF SNELLEN. A person who can see at an infinite distance reads these letters at the distance in feet corresponding with their numbers; thus, No. C is read at 100 feet; No. XL, at 40 feet; No. XX, at 20 feet. The last-mentioned number is usually selected for trial tests. The letters are placed against a wall on which falls a good light from windows opposite. (If the room be less than 20 feet in depth, No. XV may be used at 15 feet.) The person who desires to test the sharpness of his vision should be seated at a distance of 20 feet, and look at No. XX. If he can distinctly see each letter, very black and sharply defined, he has normal vision for distant objects; but this does not prove that he has normal eyes, for he may be over-sighted or far-sighted (see Hypermetropia), — a condition which gives rise to serious trouble and inconvenience, and which is by far the most frequent cause of the defective vision so common in children and young persons. (See Accommodative Asthenopia, page 198.) In order to determine whether the eyes are normal or over-sighted, put on the weakest pair of convex glasses that can be procured from the dealer, and again look at No. XX. If the vision be slightly dimmed, or the letters be less distinctly seen, the eyes are normal for distant vision (see Emmetropia); but if they still be seen as well as before the glasses were applied, then try a stronger pair; if with these the letters are seen equally well with as without them, continue changing for stronger and stronger ones until a number is found that renders the letters less sharply defined; these are a little too strong to indicate the degree of manifest over-sightedness. The rule is, the strongest pair of convex glasses with which vision is equally good with as without them, represents the degree of

over-sightedness which manifests itself. If over-sightedness exists, stronger convex glasses will be required for near vision than usually corresponds with the age. Children and young persons, whose eyes, after using them for a length of time in seeing small objects, as in reading, writing, etc., become tired, and the letters run together, are blurred and indistinct, accompanied by watering of the eyes and pain in the forehead, should always be tested for over-sightedness, which will, in a large majority of cases, be found to exist; then convex glasses should be adapted according to instructions given under the head of Accommodative Asthenopia. With proper neutralizing spectacles, their trouble will vanish, and they will soon be able to use their eyes in seeing small objects without inconvenience for an indefinite period of time. We will now suppose that the letters cannot be read at distances in feet corresponding with their numbers; that No. XX cannot be read, but only No. C, at 20 feet. It now becomes a question whether a very high grade of far-sightedness (hypermetropia), or near-sightedness (myopia), exists. To determine this point, first try weak convex spectacles; if these improve vision, and bring out another line,— say, for example, No. LXXX, — then change for a stronger pair; perhaps these render No. XL distinctly seen. Continuing to apply stronger and stronger glasses, soon a pair will be found with which No. XX can be easily read. We conclude that there is absolute far-sightedness (see Absolute Hypermetropia), and convex glasses must be constantly worn, for there can be no distinct vision either for near or remote objects without them.

In case convex glasses do not improve vision, but rather dim it, then change to concave glasses; if weak ones render the letters more distinctly seen, continue trying stronger and stronger ones, until the weakest pair is found with which No. XX. is read. These are the proper glasses to use for distant vision. Myopia, or near-sightedness, — caused by a diseased eye, — exists, and the reader is particularly

advised to read the article on this subject, commencing on page 215.

Again, eyes are sometimes met with in which vision is so defective, that the letters cannot be read at the distance in feet corresponding with their numbers, and yet neither convex nor concave glasses materially improve it. In such cases the existence of astigmatism should be suspected; tests for the determination of this anomaly of refraction are given in the chapter on Astigmatism. It requires, for correction, cylindrical or spherico-cylindrical glasses, which are not usually kept in the stocks of the smaller dealers. It is very easy to ascertain the existence of astigmatism, but it is much more difficult to determine its form and degree, and in order to adjust the proper neutralizing glasses, it requires a knowledge of the subject rarely possessed by any one except by those who make the treatment of the diseases of the eye a specialty.

Adjustment of Glasses for Near Vision of Small Objects.

All that has been said above has reference to vision of distant objects, in which the accommodation is at rest. We now come to speak of near vision, as in reading, writing, sewing, etc.

This act is accomplished by changes taking place in the eye called Accommodation. When the muscles which produce these changes fail to adjust the eyes for reading fine print at a convenient distance, or at any distance (see Presbyopia), artificial assistance must be rendered by means of convex glasses.

The test-types of Jaeger (selections from which are to be found at the end of this book) are taken as the objects for testing the powers of the accommodation to adjust the eyes for distinct vision of small near objects for a length of time.

About the middle period of life, print and other small objects cease to be distinctly seen, and must be held farther

from the eyes. Spectacles are now needed, and explicit instructions for the selection of the proper ones are given on pages 178 to 186, to which the reader is referred. The number of the spectacles should indicate the focal length of the glasses in inches; thus, No. 20 indicates a focal length of twenty inches; No. 30, thirty inches, and so on for the other numbers. The focal length of a lens is understood to be the distance at which rays of light from remote bodies,— as, for example, the sun,— falling on one of its surfaces, are united nearly in a point on a screen held on the opposite side. By measuring the distance from the lens to the focus, it is easy to ascertain if the glasses be properly numbered, and if the focal lengths of the two glasses are the same. If they do not correspond, as is often the case with cheap spectacles, they should be rejected, as also should those having bubbles or flaws in the glass, or whose surfaces are scratched. It is important to bear in mind that the so-called pebble spectacles (rock crystal) possess no advantages over those made from glass, except their hardness, which makes their surfaces less liable to be scratched, while they have certain disadvantages which render those made from glass preferable, particularly for the stronger numbers. Many of those sold for "pebbles" are made from flint-glass. (See pages 110 and 111.)

Whenever the use of spectacles for a length of time gives rise to fatigue or pain in the eyes, the proper ones have not been chosen; and if the use of them be persisted in, they will injure the organs of vision.

SELECTIONS FROM TEST-TYPES OF JAEGER.

No. 1.

We again turn from the siege of Boston, to the invasion of Canada, which at that time shared the anxious thoughts of Washington. His last accounts of the movements of Arnold, left him at Point Levi, opposite to Quebec. Something brilliant from that daring officer was anticipated. It was his intention to cross the river immediately. Had he done so, he might have carried the town by a *coup de main*; for terror as well as disaffection prevailed among the inhabitants. At Point Levi, however, he was brought to a stand; not a boat was to be found there. Letters which he had dispatched some days previously, by two Indians, to Generals Schuyler and Montgomery, had been carried by his faithless messengers, to Carambe, the lieutenant-governor, who, thus apprised of the impending danger, had caused all the boats of Point Levi to be either removed or destroyed. Arnold was not a man to be disheartened by difficulties. With great exertions he procured about forty birch canoes from the Canadians and Indians, with forty of the latter to navigate them; but stormy winds arose, and for some days the river was too boisterous for such frail craft. In the meantime the garrison at Quebec was gaining strength. Recruits arrived from Nova Scotia. The veteran Maclean, too, who had been driven from the mouth of the Sorel by the detachment under Brown and Livingston, arrived down the river with his corps of Royal Highland Emigrants, and threw himself into the place. The Lizard frigate, the Hornet sloop-of-war, and two armed schooners were stationed in the river, and guard-boats patrolled at night. The prospect of a successful attack upon the place was growing desperate. On the 13th of November Arnold received intelligence that Montgomery had captured St. Johns. He was instantly roused to emulation. His men, too, were inspirited by the news. The wind had abated; he determined to cross the river that very night. At a late hour in the

No. 2.=(No. 1 Snellen.)

We again turn from the siege of Boston, to the invasion of Canada, which at that time shared the anxious thoughts of Washington. His last accounts of the movements of Arnold, left him at Point Levi, opposite to Quebec. Something brilliant from that daring officer was anticipated. It was his intention to cross the river immediately. Had he done so, he might have carried the town by a *coup de main*; for terror as well as disaffection prevailed among the inhabitants. At Point Levi, however, he was brought to a stand; not a boat was to be found there. Letters which he had dispatched some days previously, by two Indians, to Generals Schuyler and Montgomery, had been carried by his faithless messengers, to Carambe, the lieutenant-governor, who, thus apprised of the impending danger, had caused all the boats of Point Levi to be either removed or destroyed. Arnold was not a man to be disheartened by difficulties. With great exertions he procured about forty birch canoes from the Canadians and Indians, with forty of the latter to navigate them; but stormy winds arose, and for some days the river was too boisterous for such frail craft. In the meantime the garrison at Quebec was gaining strength. Recruits arrived from Nova Scotia. The veteran Maclean, too, who had been driven from the mouth of the Sorel by the detachment under Brown and Livingston, arrived down the river with his corps of Royal Highland Emigrants, and threw himself into the place. The Lizard frigate, the Hornet sloop-of-war, and

No. 4.

two armed schooners were stationed in the river, and guard-boats patrolled at night. The prospect of a successful attack upon the place was growing desperate. On the 13th of November, Arnold received intelligence that Montgomery had captured St. Johns. He was instantly roused to emulation. His men, too, were inspirited by the news. The wind had abated; he determined to cross the river that very night. At a late hour in the evening he embarked with the first division, principally riflemen. The river was wide; the current rapid; the birch canoes, easy to be upset, required skilful management. By four o'clock in the morning, a large part of his force had crossed without being perceived, and landed about a mile and a half above Cape Diamond, at Wolf's Cove, so-called from being the landing-

No. 5.=(No. 2 Snellen.)

place of that gallant commander. Just then a guard-boat, belonging to the Lizard, came slowly along shore and discovered them. They hailed it, and ordered it to land. Not complying, it was fired into, and three men were killed. The boat instantly pulled for the frigate, giving vociferous alarm. Without waiting the arrival of the residue of his men, for whom the canoes had been despatched, Arnold led those who had landed to the foot of the cragged defile, once scaled by the intrepid Wolf, and scrambled up it in all haste. By daylight he had planted his daring flag on the far-famed Heights of Abraham. Here the

No. 7.=(No. 3 Snellen.)

main difficulty stared him in the face. A strong line of walls and bastions traversed the promontory from one of its precipitous sides to the other; inclosing the upper and lower towns. On the right, the great bastion of Cape Diamond crowned the rocky height of that name. On the left was the bastion of La Potasse, close by the gate of St. Johns, opening upon the barracks; the gate where Wolf's antagonist, the gallant Montcalm, received his death-wound. A council of war was

No. 11.=(No. 4 Snellen.)

now held. Arnold, who had some knowledge of the place, was for dashing forward at once and storming the gate of St. Johns. Had they done so, they might have been successful. The gate was open and unguarded. Through some

No. 13.=(No. 5 Snellen.)

blunder and delay, a message from the commander of the Lizard to the lieutenant-governor had not yet been delivered, and no alarm had reached the fortress. The for-

No. 14.=(No. 7 Snellen.)

midable aspect of the place, however, awed Arnold's associates.

INDEX.

ABERRATION, 27.
chromatic, 42.
spherical, 28, 41.
Abnormal astigmatism, clinical determination of, 254.
irregular astigmatism, 280.
irregular astigmatism, treatment of, 273.
regular astigmatism, 253.
Absolute hypermetropia, 191.
Accommodation, 75.
diminished by age, range of, 171.
mechanism of, 77.
muscle of, 79.
range of, 80.
relative, 83.
Accommodative asthenopia, 79, 198.
Actual inverted image, 114.
Adaptation of cylindrical lenses, 273.
Adjustment of glasses for near vision of small objects, 283.
of spectacles, 107.
Aerial perspective, 159.
After-images, 133.
Ametropia, 97.
Anatomical changes in the fundus oculi in myopia, 225.
construction of the eye, 69.
Anatomy of the retina, 123.
Anerythropsia, 130.
Angle of incidence, 28.
of refraction, 28.
refracting, 44.
Aphakia, 213.
Asthenopia, 198.
accommodative, 198.
muscular, 198, 231.
Astigmatism, 97, 247.
abnormal irregular, 280.
abnormal regular, 253.
compound hypermetropic, 272.
compound myopic, 271.
forms of, 271.
irregular, 278.
lenticular, 70.
mixed, 272.
normal irregular, 278.
normal regular, 253.
simple hypermetropic, 272.
simple myopic, 271.

BASE line, 149.

CALCULATIONS, dioptrical, 86.
Calorescence, 52.
Cardinal points, 87.
Centre of rotation, 147.
Change in the eye with the advance of age, 169.
Chromatic aberration, 42.
Ciliary muscle, 79.
Clinical determination of abnormal astigmatism, 254.
Color-blindness, 130.
Colors, fundamental, 129.
of thin plates, 63.
simple, 126.

Comparative frequency of myopia in different classes of society, 219.
Comparison between the intensities of lights of different colors, 137.
Complementary colors, 127.
Compound colors, 127.
hypermetropic astigmatism, 272.
myopic astigmatism, 271.
Concave spectacles, 98, 241.
Congenital predisposition to myopia, 224.
Conjugate foci, 27.
and relation between magnitude B of the object and magnitude β of the image, 94.
Constants, optical, 90.
Convergence, 82.
relative, 83.
Convergent squint, 209.
Convex spectacles, 98.
Crossed diplopia, 101.
Curved surfaces, reflection from, 25.
refraction by, 34.
Cylindrical glasses, spectacles with positive or negative, 100.

DARK or invisible rays, 51.
Definitions, 19.
Depth and solidity, estimation of, 153.
Determination of hypermetropia and its degree by means of the ophthalmoscope, 191.
Difference in refraction of the two eyes, 283.
Diffraction, or the inflection of light, 61.
Diminution of light by distance, law of, 21.
Dioptrical calculations, 86.
Dioptrics of the eye, 68, 72.
Direct influence of glasses with spherical surfaces on vision, 103.
Diverging strabismus, 234.
Double refraction, 65.
Dyschromatopsia, 130.

ELASTIC steel spectacles, 104.
ether, 17.
Emission theory, 46.
Entoptic perception of the retinal vessels, 118.
phenomena, 115.
Errors of refraction and defects of accommodation, 168.
Estimation of depth and solidity, 153.
Examination of the eyes of school-children, 222.
Extent of line of relative convergence, 84.
of the line of relative accommodation, 86.
Eye, anatomical construction of the, 69.
dioptrics of the, 68, 72.
Eye-glasses, 108.
Eye-protectors, 106.
wire gauze, 107.
Eyes, movements of the, 146.

FACULTATIVE hypermetropia, 191.
Field of vision, measurement of the, 125.
Fluorescence, 53.
Focal distance, 25.
Formation of images, 39.
Form, position, and movements of the hypermetropic eye, 193.
Forms of astigmatism, 271.
Fovea centralis, 74.
Fraunhofer's lines, 56.
Fundamental colors, 129.

GLASSES à double foyer, 99.

HOMOCENTRIC light, 19.
Homonymoms, 101.
Horizontal meridian, 147.
Horopter, 151.
Hypermetropes, vision of, 195.
Hypermetropia, 97, 187.
absolute, 191.

Hypermetropia, facultative, 191.
relative, 191.
treatment of, 201.
Hypermetropic eye, form, position, and movements of the, 193.

ILLUSIONS of ocular estimation, 162.
Images, formation of, 39.
formed by reflection from curved surfaces, 26.
Incidence, angle of, 28.
Inclined surfaces, refraction at, 44.
Index of refraction, 29.
Inflection of light, 61.
Instructions for the adaptation of spectacles, 285.
Insufficiency of the internal recti muscles, 231.
Intensities of lights of different colors, comparison between the, 137.
Intensity of luminous sensations, 135.
Interference, phenomena of, 58.
Irradiation, 138.
Irregular astigmatism, 278.

LAW of diminution of light by distance, 21.
of identical retinal points, 151.
Lenses, 34.
Lenticular astigmatism, 70.
Light, 17.
beam of, 17
homocentric, 19.
movement of, 19.
pencil of, 19.
ray of, 19.
reflection of, 22.
refraction of, 28.
theories of, 46.
velocity of, 22.
London smoke glass spectacles, 102.
Luminous sensations, intensity of, 135.

MACULA lutea, 73.
Magnitude and distance, ocular estimation of, 154.
Measurement of the field of vision, 125.
of the waves of light, 64.
Mechanism of accommodation, 77.
Median plane, 150,
Meridian, horizontal, 147.
vertical, 147.
Method by the phenomena of dispersion, 269.
of Dr. Thompson, 266.
of Risley, 263.
of Strawbridge, 258.
of the stenopæic slit, 269.
Methods of Young and Graefe, 268
Mixed astigmatism, 272.
Movements of the eyes, 146.
Muscæ volitantes, 117.
Muscle of accommodation, 79.
Muscular asthenopia, 198, 231.
mesoropter, 150.
Myopia, 97, 215.
anatomical changes in the fundus oculi in, 225.
at a distance, 225.
congenital predisposition to, 224.
in different classes of society, comparative frequency of, 219.
treatment of, 237.

NEAR-SIGHTEDNESS, 215.
Near-sighted persons, vision of, 228.
Near vision of small objects, adjustment of glasses for, 289.
Normal irregular astigmatism, 278.
regular astigmatism, 253.
Nuclear-point, 151.
Nuclear-surface, 151.

OCULAR estimation, illusions of, 162.
of magnitude and distance, 154.
Ophthalmoscope, the, 113.
Optical constants, 90.
Optics, physical, 17.
physiological, 68.

PENUMBRA, 20, 116.
Perceptions, visual, 140.
Periscopic spectacles, 98.
Persistence of retinal impressions, 132.
Perspective, aerial, 159.
Phacoidoscope, 77.
Phenomena, entoptic, 115.
of dispersion, method by the, 269.
of interference, 58.
Phosphenes, 120.
Phosphorescence, 55.
Physical optics, 17.
Physiological optics, 68.
Plane mirrors, 22.
Points, cardinal, 87.
Polarization, 65.
Position and character of reflected images in plane mirrors, 24.
Posterior staphyloma, 220.
Presbyopia, 97.
treatment of, 178.
Prismatic dispersion, 50.
spectrum, 45.
Protecting spectacles, 101.
Pseudoscope, the, 166.
Pulpit spectacles, 105.
Punctum coecum, 121.
Pure spectrum, 55.

QUADRANTS, 147.

RANGE of accommodation, 80.
diminished by age, 171.
Reflected images in plane mirrors, position and character of, 24.
Reflection from curved surfaces, 25.
images formed by, 26.
of light, 22.
total, 31.
Refracting angle, 44.
Refraction and defects of accommodation, errors of, 168.
angle of, 28.
at inclined surfaces, 44.
by a spherical surface, 92.
Refraction by curved surfaces, 34.
double, 65.
index of, 29.
of light, 28.
of the two eyes, difference in, 283.
Relative accommodation, 83.
extent of the line of, 86.
convergence, 83.
convergence, extent of line of, 84.
hypermetropia, 191.
Retina, anatomy of the, 123.
Retinal impressions, persistence of, 132.
points, law of identical, 151.
vessels, entoptic perception of the, 118.
Risley, method of, 263.
Rotation, centre of, 147.

SELECTION of spectacles, 110.
Selections from test-types of Jaeger, 291, 293.
Sensations, visual, 120.
Shadows, 20.
Simple colors, 126.
hypermetropic astigmatism, 272.
myopic astigmatism, 271.
Solar spectrum, 45.
Spectacle frames, 104.
Spectacles, adjustment of, 107.
and their uses, 97.
concave, 98, 241.
convex, 98.
elastic steel, 104.
instructions for the adaptation of, 286.
London smoke glass, 102.
periscopic, 98.
prismatic, 100.
protecting, 101.
pulpit, 105.
with positive or negative cylindrical glasses, 100.
Spectroscope, 56.

Spectrum analysis, 55.
prismatic, 45.
solar, 45.
Spherical aberration, 28, 41.
surface, refraction by a, 92.
Squint, convergent, 209.
Stenopæic slit, method of the, 269.
Stereoscope, the, 163.
Strabismus, diverging, 234.
Strawbridge, method of, 258.

TEST-TYPES used by Jaeger, 291, 293.
Theories of light, 46.
Thin plates, colors of, 63.
Thompson, Dr., method of, 266.
Total reflection, 31.
Transparency and opacity, 19.
Treatment of abnormal regular astigmatism by the adaptation of cylindrical lenses, 273.
of hypermetropia, 201.
of myopia, 237.
Treatment of presbyopia, 178.
Turn-pin temples, 105.

UNDULATION theory, 47.

VELOCITY of light, 22.
Vertical meridian, 147.
Vision, direct influence of glasses with spherical surfaces on, 103.
of hypermetropes, 196.
of near-sighted persons, 228.
Visual line, 151.
perceptions, 140.
sensations, 120.

WAVES of light, measurement of the, 64.
Why does the pupil of the eye appear black? 111.
Wire-gauze eye-protectors, 107.

YOUNG and Graefe, methods of, 268.

THE END.

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CLASSIFIED INDEX

TO

LINDSAY & BLAKISTON'S PUBLICATIONS.

ANATOMY.

Rindfleisch's Text-Book of Pathological Histology. ... 28
Wilson's Anatomist's Vade Mecum ... 37
Handy's Text-Book of Anatomy ... 18
Hilles's Pocket Anatomist ... 19
Jones and Sieveking's Pathological Anatomy ... 20
Holden's Manual of Dissections ... 18
" Human Osteology ... 18
Wilks & Moxon's Pathological Anatomy ... 36
Bradley's Comparative Anatomy ... 7
Reeves' Practical Histology ... 29

BRAIN AND NERVOUS SYSTEM.

Bucknill and Tuke's Psychological Medicine ... 9
Radcliffe on Epilepsy, Paralysis, &c. ... 29
Tuke's Influence of the Mind on the Body 35
Elam on Cerebria ... 15
Sheppard on Madness ... 32
Sankey's Lectures on Mental Diseases ... 31
Van der Kolk's Pathology and Therapeutics of Mental Diseases ... 63

CHEST, HEART, THROAT, ETC.

Waters on the Chest ... 38
Fothergill on the Heart ... 15
Stokes on the Heart and Aorta ... 31
Cohen on Inhalation ... 11
Greenhow on Bronchitis ... 17
Mackenzie on the Throat and Nose ...
Mackenzie on Growths in the Larynx ... 22
Mackenzie on the Laryngoscope in Diseases of the Throat ... 22
Mackenzie's Pharmacopœia of the Hospital for Diseases of the Throat ... 22
Thorowgood on Asthma ... 35
Barth and Roger on Auscultation and Percussion ... 7
Dobell on Winter Cough ... 13
Ruppaner's Laryngoscopy ... 30
Cohen on Croup ... 11

CHILDREN (DISEASES OF).

Meigs and Pepper's Practical Treatise on Diseases of Children ... 23
Tanner and Meadows's Diseases of Infancy and Childhood ... 33
Ellis's Practical Manual of the Diseases of Children ... 15
Hillier's Clinical Treatise on Children ... 18

CANCER.

Marsden's New Mode of Treating Cancer 25
Arnott on Cancer ... 6

CHEMISTRY, BOTANY, ETC.

Bloxam's Chemistry, Inorganic & Organic 8
" Laboratory Teaching ... 8
Murphy's Review of Chemistry ... 23
Reese's Syllabus of Chemistry ... 29
Darlington's Flora Cestrica ... 14
Bentley and Trimen's Medicinal Plants.
Frankland's How to Teach Chemistry... 16
Sutton's Volumetric Analysis ... 32

DEFORMITIES.

Adams on Club-Foot ... 6
Brodhurst on Deformities ... 9
Prince's Plastic and Orthopedic Surgery. 27
" Galvano-Therapeutics ... 27

DENTAL SCIENCE.

Harris's Principles & Practice of Dentistry 18
" Dictionary of Dental Surgery... 18
Richardson's Mechanical Dentistry ... 29
Taft's Operative Dentistry ... 33
Tomes's Dental Surgery ... 35
" Dental Anatomy and Physiology 35
Wedl's Dental Pathology ... 37
Leber and Rottenstein on Dental Caries. 21
Coles's Mechanical Dentistry ... 12
" Deformities of the Mouth ... 12
Heath's Injuries and Diseases of the Jaws 19
Fox on the Human Teeth ... 16
Robertson on Extracting Teeth ... 29

DICTIONARIES.

Harris's Dictionary of Dental Surgery and Medical Terminology ... 18
Sweringen's Pharmaceutical Lexicon ... 32
Cooper's Surgical Dictionary ... 11
Cleaveland's Pronouncing Medical Lexicon 12

EYE AND EAR.

Soelberg Wells on Diseases of the Eye... 38
" on Long, Short, and Weak Sight ... 38
Lawson's Diseases and Injuries of the Eye 21
Macnamara's Manual of Diseases of the Eye ... 22
Dixon's Guide to Diseases of the Eye ... 14
Walton's Surgery and Diseases of the Eye 38
Liebreich's Ophthalmoscopic Atlas ... 21
Jones on Defects of Sight and Hearing... 20
Power's Student's Guide to Diseases of the Eye ... 26
Dalby on Diseases and Injuries of the Ear 15
Toynbee on the Ear, by Hinton ... 34

ELECTRICITY.

Tibbitts's Hand-Book of Medical Electricity 35
Althaus's Medical Electricity 6
Reynolds's Clinical Uses of Electricity... 28
Duchenne's Localized Electrization 14

FEMALES (DISEASES OF).

Hewitt's Diagnosis, Pathology and Treatment of the Diseases of Women 17
Byford's Medical and Surgical Diseases of Women 9
Byford on the Uterus 9
Atthill's Clinical Lectures on Diseases of Women 6
Dillenberger's Handy-Book of Women and Children's Diseases 14
Agnew's Lacerations of the Female Perineum 6
Tilt's Change of Life in Women 34
Savage's Female Pelvic Organs 32
" Nature of the Surgical Diseases of the Female Pelvic Organs 32
Scanzoni's Diseases of Women 31
Hodge on Fœticide and Abortion 20

FEVERS.

Stillé's Epidemic Meningitis 31
Flint on Continued Fever 16

FORENSIC MEDICINE & TOXICOLOGY.

Woodman and Tidy's Hand-Book of Forensic Medicine 38
Tanner's Memoranda of Poisons 33

GENERATIVE & URINARY ORGANS, SYPHILIS, ETC.

Acton on the Reproductive Organs 7
" on Prostitution 7
Black on the Functional Diseases of the Renal, Urinary & Reproductive Organs 10
Harley on the Urine & its Derangements 17
Legg on Examination of the Urine 21
Thompson on the Urinary Organs 34
" on Calculous Diseases 34
Lewin on the Treatment of Syphilis 22
Durkee on Gonorrhœa and Syphilis 14
Parker's Modern Treatment of Syphilis. 27
Gant's Irritable Bladder 16
Buzzard's Syphilitic Nervous Affections. 7
Tyson on Examination of Urine 33

HYGIENE AND POPULAR MEDICINE.

Parkes's Practical Hygiene 26
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